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The Canada-Alberta Forest Resource Development Agreement is a subsidiary agreement of the Canada-Alberta Economic and Regional Development Agreement, which provides coordination and cooperation between the governments of Alberta and Canada in areas of Alberta's economic development.

The Canada-Alberta Forest Resource Development Agreement is funded equally by the governments of Canada and Alberta, from April 1, 1984, to March 31, 1989.

Its primary objectives are to ensure the long-term availability of timber supplies; to optimize timber uses; and to contribute to the growth and diversification of Alberta's economy.

The Agreement comprises three programs: Reforestation; Applied research, technology transfer and opportunity identification; and Public information, evaluation and administration. These programs are managed by a joint Directorate and are implemented by the Canadian Forestry Service and the Alberta Forest Service.

L'Entente Canada-Alberta sur la mise en valeur des ressources forestières est auxiliaire à l'Entente Canada-Alberta sur le développement économique et régional, qui vise à assurer la coordination et la coopération des deux gouvernements relativement au développement économique de l'Alberta.

L'Entente Canada-Alberta sur la mise en valeur des ressources forestières est financée à parts égales par les gouvernements du Canada et de l'Alberta, et a cours du 1er avril 1984 au 31 mars 1989.

Ses objectifs principaux sont assurer la disponibilité à long terme de réserves de bois; optimiser leur utilisation; et contribuer à la croissance et la diversification de l'économie de la province.

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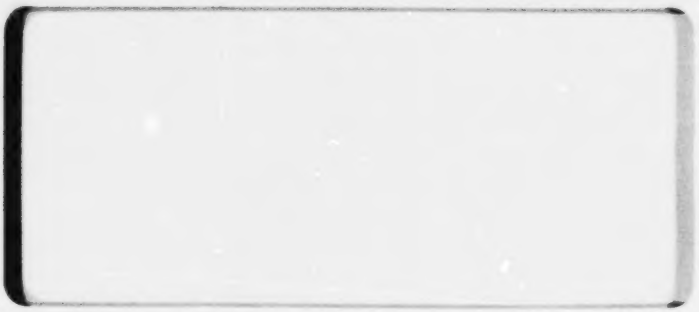

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RISK MANAGEMENT IN FOREST PLANNING

W.R. Dempster & Associates Ltd.[1]
1987

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ABSTRACT

A review of literature indicated that the needs for appropriate forest management and research activities in response to risk are not well defined.

The importance and relevance of risk of timber losses to fire, insects, and disease were examined in relation to industrial forest management in Alberta. Based on the distribution of historic fire rates, the probability of realizing deterministically projected volumes over time was simulated in a harvest-scheduling model. The relationship of stand and site attributes to fire occurrence was investigated using inventory data from fire-origin stands in west-central Alberta.

A meeting of expert managers and researchers was held to interpret results, coalesce ideas, and guide further enquiries. Subsequently, the adjustment of harvest sequences to reduce risk was further investigated, and available information on biotic damage was reviewed in more detail.

The implications of risk are discussed in relation to harvest schedules, investment decisions, and to boreal forest management in general. Recommendations are made concerning the integration of risk management into forest management, research, and education.

ACKNOWLEDGEMENTS

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A number of people contributed significantly to the study by participating in individual and group discussions, identifying relevant literature, and providing data and suggestions. Particular thanks are owed to M. Alexander, R. Barney, Z. Chrosciewicz and H. Cereske of the Canadian Forestry Service, P. Murphy of the University of Alberta, D. Quintilio of the Forest Technology School, Hinton, C. Smith of the Alberta Department of Forestry, Lands and Wildlife and R. Udell and J. Wright of Champion Forest Products Limited.

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1. INTRODUCTION

In the boreal forests of Canada, increasing emphasis is being placed on the optimum utilization of timber resources under sustained-yield management. Decisions regarding the immediate allocation and management of timber are predicated on assumptions and predictions spanning one or more rotations. Ironically, while it is generally recognized that timber supplies and silvicultural investments are subject to risk,* most, if not all, planning models used in timber supply forecasting are purely deterministic, essentially ignoring risk.

Clarifying the role and relevance of risk in forest management is a complex interdisciplinary problem. Perhaps it is for this reason that methods of decision-making under risk or uncertainty have not been widely applied in forest management (Fight and Bell 1977). The information required for rational decision-making under risk is frequently unavailable, due in part to the lack of perceived need.

Many of the issues and approaches to risk in forestry are poorly understood and this lack of understanding impedes the application of risk management techniques. This study examines the existing status of our knowledge of risk in forestry and attempts to define its role in industrial forest management today. The interrelationships of various aspects of forest management including fire behavior, harvest scheduling, entomology, pathology, and operations research are considered.

A number of management techniques were identified which were thought to have a potentially high impact on rational decision-making under risk. Because of the poor level of understanding of risk in forestry, these techniques were considered worth demonstrating in a specific management context. The objectives of this study were to (1) assess the importance of risk of destruction by such agents as fire, insects and disease, and (2) evaluate and demonstrate techniques for managing risk, in relation to industrial forest management in Alberta. Specifically the study attempted to determine the relationship of risk to timber supply, rotation length and stand and locational attributes. The existence of such relationships would infer that expected volume loss from risk is dependent on forest management strategies and the sequence in which stands are harvested. The McLeod Working Circle within the lease area of Champion Forest Products (Alberta) Limited was used as the case study area.

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* Risk as used in this report refers to the probability of an event (generally destructive) generated by a hazard, over a specified period of time.

2. LITERATURE REVIEW

The literature pertaining to risk in timber management is not extensive. For the purposes of this review, the research is divided into two broad groups, although it is recognized that this discrete classification is somewhat arbitrary:

1. Effect of the risk of fire;

2. Effect of other risk, including insect and disease loss and probabilistic growth.

A further classification is warranted since decision-making in timber management is generally divided into stand level and forest level decisions. In stand level management, each individual stand can be managed independently of all other stands. Forest level management refers to planning which must be coordinated for all stands in the forest. Frequently forest level constraints such as maintaining an even-flow of timber supply preclude optimal stand level management.

2.1 EFFECT OF THE RISK OF FIRE

2.1.1 Stand Level Analyses

Martell (1980) examined the optimal rotation of a forest stand subject to fire using dynamic programming. For any given year, there was a probability that the stand would burn, a revenue generated if the stand were cut without fire occurring, and a salvage revenue if the stand were burned. The objective was to maximize expected present value over an infinite planning horizon. Martell showed that as the probability of fire increased, optimal rotation and expected present value decreased.

Routledge (1980) developed a modified version of Faustmann's (1849) equation to determine optimal rotation for a stand subject to risk of destruction. Growth was balanced against the interest lost by postponing the harvest as well as the potential loss of revenue resulting from stand destruction. In general, optimal rotation ages decreased with increasing probabilities of destruction.

Reed (1984) mathematically proved that fire caused an increase in discount rate by an amount equal to the long-term average rate of fire occurrence. Fires were assumed to cause complete destruction and occur in a Poisson fashion.

As an extension to these mathematical results, Reed and Errico (1984) determined long-term average yields for various rotation ages. The formula below indicates the procedure:

$$Y'(T) = \frac{pY(T)}{e^{pT} - 1}$$

where: $Y'(T)$ = long-term average yield at rotation T
p = annual probability of fire
$Y(T)$ = yield at time T with no fire

A "volume-rotation" curve can be derived from this relationship for any fire rate. Higher levels of annual loss resulted in lower optimal cutting ages and lower long-run average yields.

2.1.2 Forest Level Analyses

Van Wagner (1983a) used simulation to assess the effects of fire on long-term timber supply. Fire was assumed to burn a constant area yearly and harvesting also occurred on an area basis. His major conclusion was that the amount by which the maximum sustainable harvest (with no fire) was reduced by fire was substantially greater than the volume of timber burned.

Reed and Errico (1986) used linear programming to determine the effect of fire on forest-level management. Their approach was similar to other commonly used harvest scheduling models such as Timber RAM (Navon 1971) in that current harvest rates were constrained by the long-term sustained yield. By assuming constant rates of destruction, a deterministic solution to the problem of fire in harvest scheduling was developed. This deterministic solution was thought to approximate the stochastic fire situation providing that the variability in fire rates is small. Substantial reductions in long-term harvest levels were indicated.

The forest-level studies of Van Wagner (1983a) and Reed and Errico (1986) indicate the large significance that fire can have on timber supply. However, their studies are not necessarily directly applicable to current harvest policies, since determination of the optimal transition to the long-term harvest rate is not possible with either method.

Stevens (1986) examined this problem of optimal current harvest rates through the use of probabilistic dynamic programming. The common belief that reductions in harvest level will reduce future fluctuations in harvest level was critically examined. Stevens found that very substantial amounts of harvest had to be relinquished in order to decrease fluctuations in harvest appreciably. Frequent replanning was shown to be a good method of dealing with risk and uncertainty.

2.2 EFFECT OF OTHER RISKS

2.2.1 Stand Level Analyses

Perhaps the first attempts at incorporating risk into timber management began with the recognition of the probabilistic nature of growth. Hool (1966) examined probabilistic growth response in relation to activities of clearcutting, selection harvesting and thinning. The objective of his finite stage dynamic programming model was to maximize the volume harvested over various planning horizons.

Lembersky and Johnson (1975) examined a similar stand management problem but included uncertainties in future product markets as well as uncertainties in stand response. The problem was modelled as an infinite horizon Markov decision process, maximizing total discounted expected return. Lembersky (1976) expanded his approach to maximize average annual merchantable volume. He developed a chart indicating expected stand production given various management activities such as various harvesting and thinning intensities.

Kao (1982) used dynamic programming to solve the joint optimization problem of stocking level and rotation length under assumptions of probabilistic growth. His results on rotation length concur with those of Routledge (1980), Martell (1980), and Reed and Errico (1984). Kao (1984) extended his model formulation to improve decision-making under uncertainty. Through the periodic revision of a growth function he was able to utilize information generated from previous stages. This lead to the gradual transition of decision-making under uncertainty to decision-making under risk.

2.2.2 Forest Level Analyses

A combination of simulation and linear programming (LP) was used by Thompson and Haynes (1971) to model the risk associated with future availabilities of land and timber. The objective was to satisfy the wood requirements to a mill while minimizing cost.

Weintraub (1976) used a LP formulation similar to Timber RAM (Navon 1971) to model probabilistic growth. Constraints were satisfied with a predetermined probability of success and the solution determined in an iterative fashion.

Johnson and Stuart (1984) discuss a modification to FORPLAN which allows for multiple outcomes from differing regeneration success and stand mortality in a decision tree approach.

Reed and Errico (1987) formulated a solution procedure to deal with pest hazards similar to the one they used for fire. They provided an example using mountain pine beetle. While admitting that their study was not a comprehensive analysis of pest hazard, they concluded that the impact of the mountain pine beetle in their case study area on long-term timber supply was not great. However, short-term effects may be very dramatic.

2.3 RELEVANCE TO FOREST MANAGEMENT

The existing knowledge of the effect of risk and uncertainty in timber management leads to several important conclusions. The first is that even relatively low rates of destruction in conjunction with harvesting will, in the long run, mean substantially lower rates of harvest than are expected now. Stevens (1986) forecast a long-term average rate of harvest 26% lower than the anticipated sustained yield for an average annual fire rate of 0.15%. Reed and Errico (1986) predicted a 40% loss in sustained yield with a constant 1% annual rate of loss and Van Wagner's (1983a) forest level research indicated a 30% loss in sustained yield for a constant fire rate of 1%. The differences in magnitude of the effects are partially related to assumptions regarding the variability in fire rates. Regardless, the predicted decreases in long-term harvest rates do indicate the seriousness of the risk of destruction. Given the long term effects that are forecast, the importance of reducing rates of destruction and/or minimizing their effect through harvesting practices and risk management techniques is very high.

Some of these techniques have already been demonstrated. For example, Stevens (1986) showed that forest level constraints do not justify

the reduction of harvest rates unless an extremely high value is placed on reducing the magnitude of fluctuations in harvest level over time. In fact, increases in harvest rates through the reduction of rotation length are recommended when maximum long-term productivity is desired (Reed and Errico 1984, Routledge 1980, Martell 1980, Kao 1982).

As Reed and Errico (1984) demonstrated, the failure to recognize risk and reduce rotation age accordingly will mean that maximum long-term productivity is not achieved. They showed that long-term productivity was reduced 6% when risk was not incorporated into rotation determination (a 1% annual rate of destruction was assumed). The reduction of rotation age is not a panacea; it is merely one element to be considered in a rational risk management scheme.

The need for risk management is apparent. Relatively low rates of destruction can have major long-term effects. In addition the short-term effects of stochastic destruction are obvious; the mountain pine beetle infestation in southern Alberta and British Columbia, the spruce budworm in Eastern Canada, and the record levels of fire in Alberta in 1981 are just a few examples where the effect on local timber supply can be drastic. However, risk has not generally been considered in forest management decisions and research regarding risk in forestry is relatively new. The result is that the emphasis and need for appropriate management activities and research are not well defined.

3. QUANTITATIVE ANALYSES

The quantitative analyses performed in this study relate mostly to the risk of destruction by fire. Historically, fire was the main cause of catastrophic mortality in northern forests and its dominance continues. As a result reasonable fire records have been kept which makes the estimation of the probabilities associated with fire possible. In addition, quantification of the effect of fire on timber supply has strong implications for both fire and timber management.

Forest fire is a stochastic process characterized by extreme variability. The area burned in Alberta based on reported fires from 1918 to 1983 is shown in Figure 1 as an example. Variability will increase further if smaller land units are considered (Van Wagner 1983a). For example, in Tande´s (1977), study of fire history in the Jasper area, three years over a 300 year period were found in which annual rates of burn exceeded 50%, whilst the average rate was only 0.98%. The increase in variability with small land units is especially important for timber supply analyses, since annual allowable cuts (AACs) are determined for relatively small land areas; for example in Alberta, AACs are based on a land unit whose size is commonly 200 000 to 300 000 hectares.

Arithmetic averages of fire rates are somewhat meaningless given this high variability. Averages mask the variability inherent in the process, and in general, it is the extreme fire conditions which are most important. To overcome this problem of variability and of basing forecasts of burned area on a relatively short historic record, a statistical distribution was fit to the historic record being considered. This method preserves some of the statistical properties of the original record such as mean and variance. It is in common use in many fields such as flood frequency* analysis and has been used in the modelling of fire weather index (Fujiok and Tsou 1985) and fire rates previously (Stevens 1986).

Ideally fire frequency curves should be based on the stratification of areas by fire regime. In this study, ecoregions were used to approximate this stratification. However, because of limitations imposed by the form of the fire data, a fire frequency curve was prepared for the entire East Slopes as approximated by the Edson Forest, the Rocky-Clearwater Forest and the Bow-Crow Forest. The other seven provincial forests were assumed to be in the boreal area. The length of record used was 1961 - 1986 (refer to Figures 2 and 3). The two fire frequency curves were used in subsequent analyses to determine the expected average annual timber harvest. In addition, fire frequency curves were derived for the Edson Forest (1961 - 1986) and for the province of Alberta for two time periods, 1961 - 1986 and 1918 - 1960.

Because of the increasing variability of fire rates with smaller land units, it is desirable that the fire frequency curve be based on the

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* Frequency as used in this report refers to number of individuals in a single class when objects are classified according to variations in a set of one or more specified attributes (Websters´ New Collegiate Dictionary, 1977).

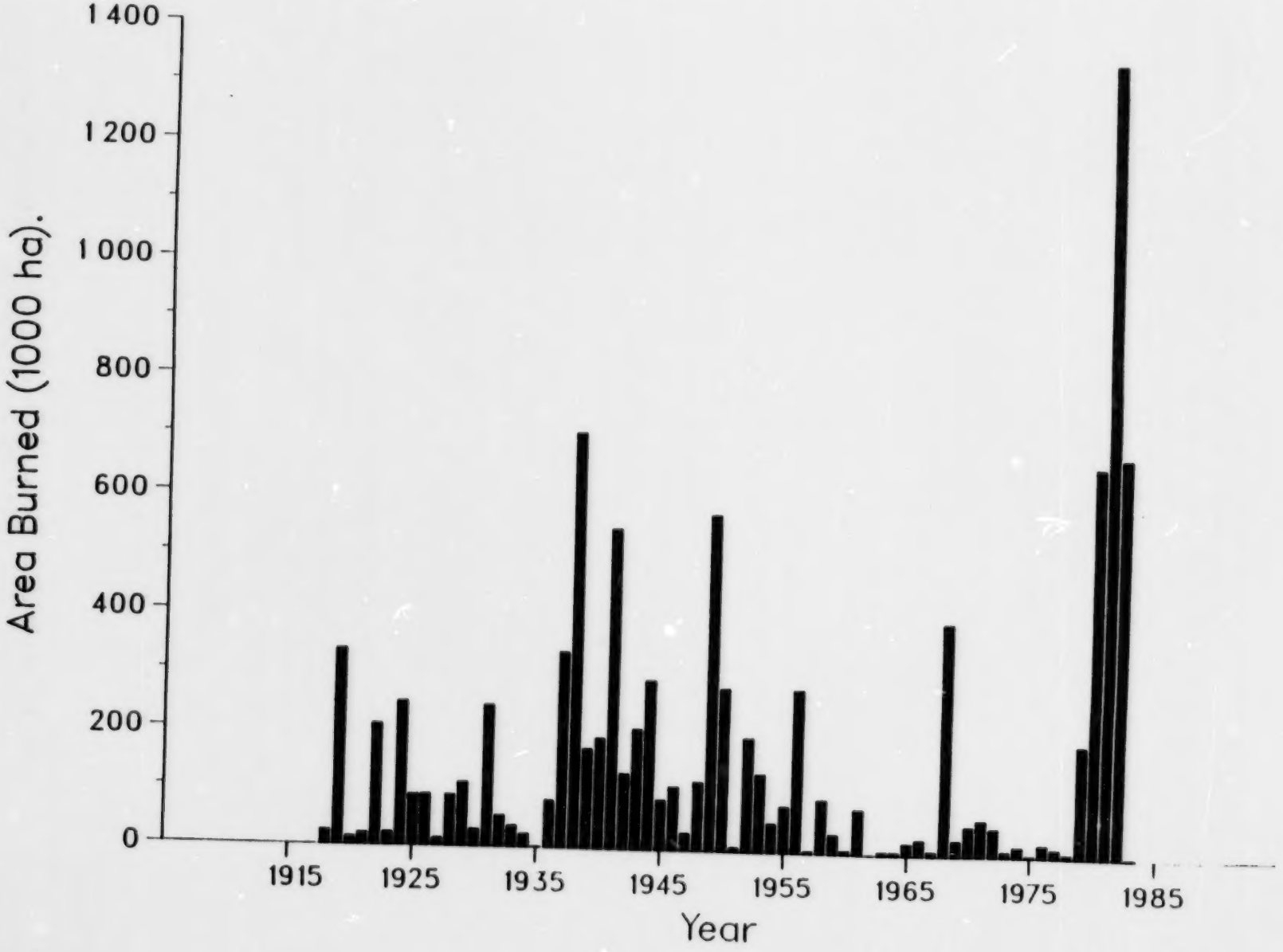

Figure 1: Burned area in Alberta 1918 - 1983
(from Stocks and Barney 1981, Murphy 1985)

size of land unit which is to be modelled. For example, in this study, the McLeod Working Circle* is the basic land unit. However, rather than only the historic record for the McLeod being used, accuracy of the fire frequency curve would be improved if a regional or composite fire frequency curve were made. This would entail dividing up the broad ecoregion into land units similar in size to the McLeod Working Circle, deriving a fire frequency curve for each and then averaging the parameters of the distributions to produce a composite distribution. Data and time limitations prevented this approach for this study.

The fire frequency curves for the two ecoregions used in this study are shown in Figure 4. Each rate of fire has a probability associated with it; high fire rates occur less commonly and therefore have low probabilities of occurrence. The return period is equal to the reciprocal of the probability of a rate being equalled or exceeded. For example, the return period of an annual fire rate of 0.01% is approximately 1.2 years for the boreal area, 3 years for the East Slopes area, and 4 years for the Edson Forest. The return period is the average recurrence interval and does not denote periodicity. The steeper the slope of the lines, the lower the variability in fire rates. Thus the historic record for the East Slopes has shown less variability than the boreal area. The rates on the East Slopes were also much less severe than those found in the boreal area. The frequency curve for the Edson Forest is also shown.

Figure 5 compares long-term historic and short-term fire frequency for the entire province. The rates indicated by both curves are similar except that greater variability in rates is present in the short-term record. The distributions shown in Figures 4 and 5 are log-normal (Cooper and Weekes 1983) and all were judged to be valid models at the 0.05 level of probability by a Chi-square test.

The process of harvest scheduling is concerned with future supplies of timber and therefore the impact of fire should be assessed in terms of potential fire behavior, not past fire behavior. To simulate hypothetical future fire rates, random annual rates of fire were produced from the fire frequency curves. The Box-Muller method (Box and Muller 1958) was used to obtain normally distributed random numbers which are required to generate random annual rates of fire from the log-normal distributions.

For the East Slopes area and boreal area fire frequency curves, four thousand different 90 year fire sequences were produced. Ninety-year sequences were chosen because ninety years is the rotation currently being considered for management of the McLeod Working Circle. The cumulative probability of a stand surviving for 90 years was determined from each 90 year fire sequence by the formula:

$$\text{Cumulative probability of survival} = 1 - \prod_{i=1}^{90} (1 - P_i)$$

where P_i = annual probability of fire

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* A portion of Champion Forest Products (Alberta) Ltd. lease area

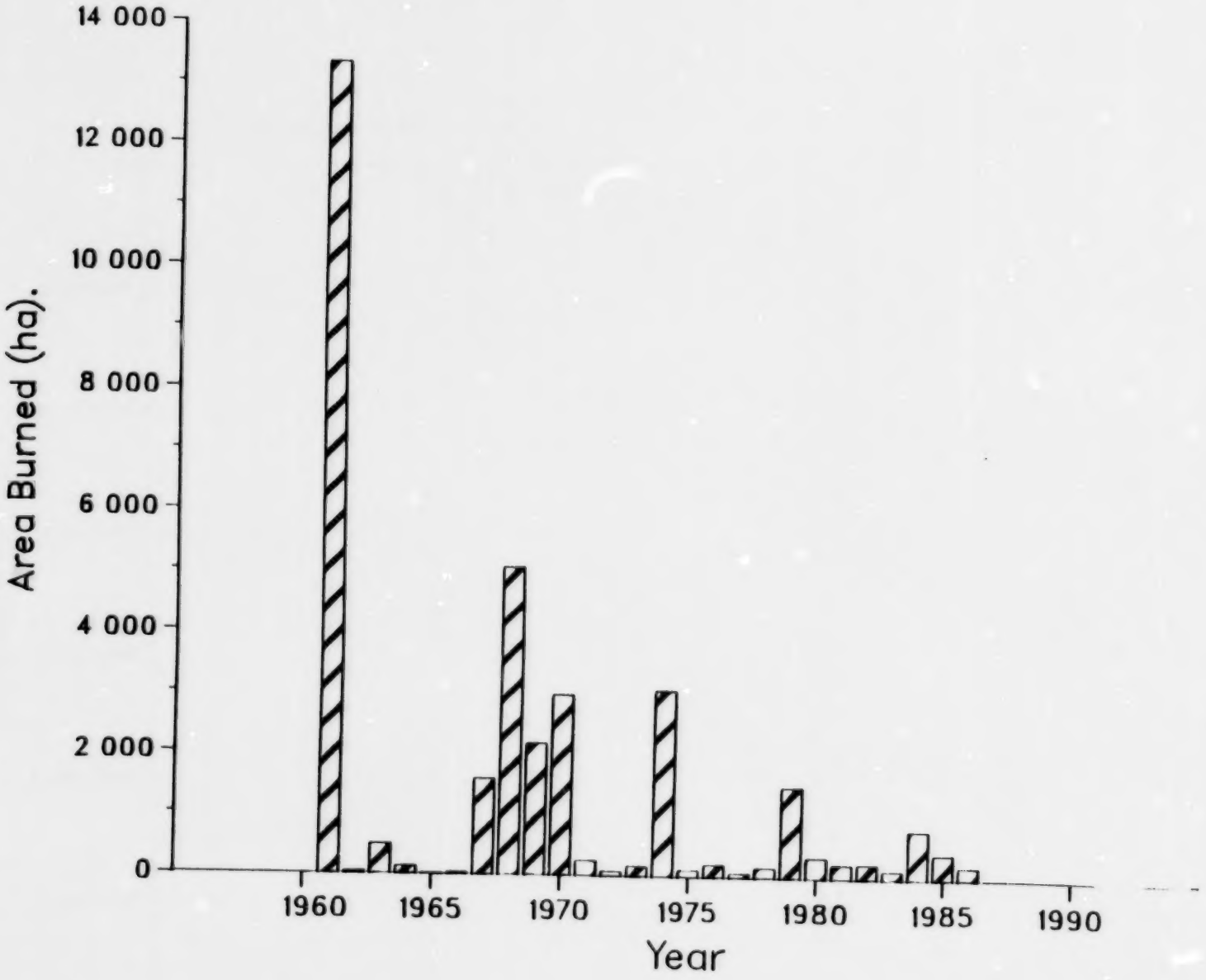

Figure 2: Burned area in the East Slopes 1961 - 1986

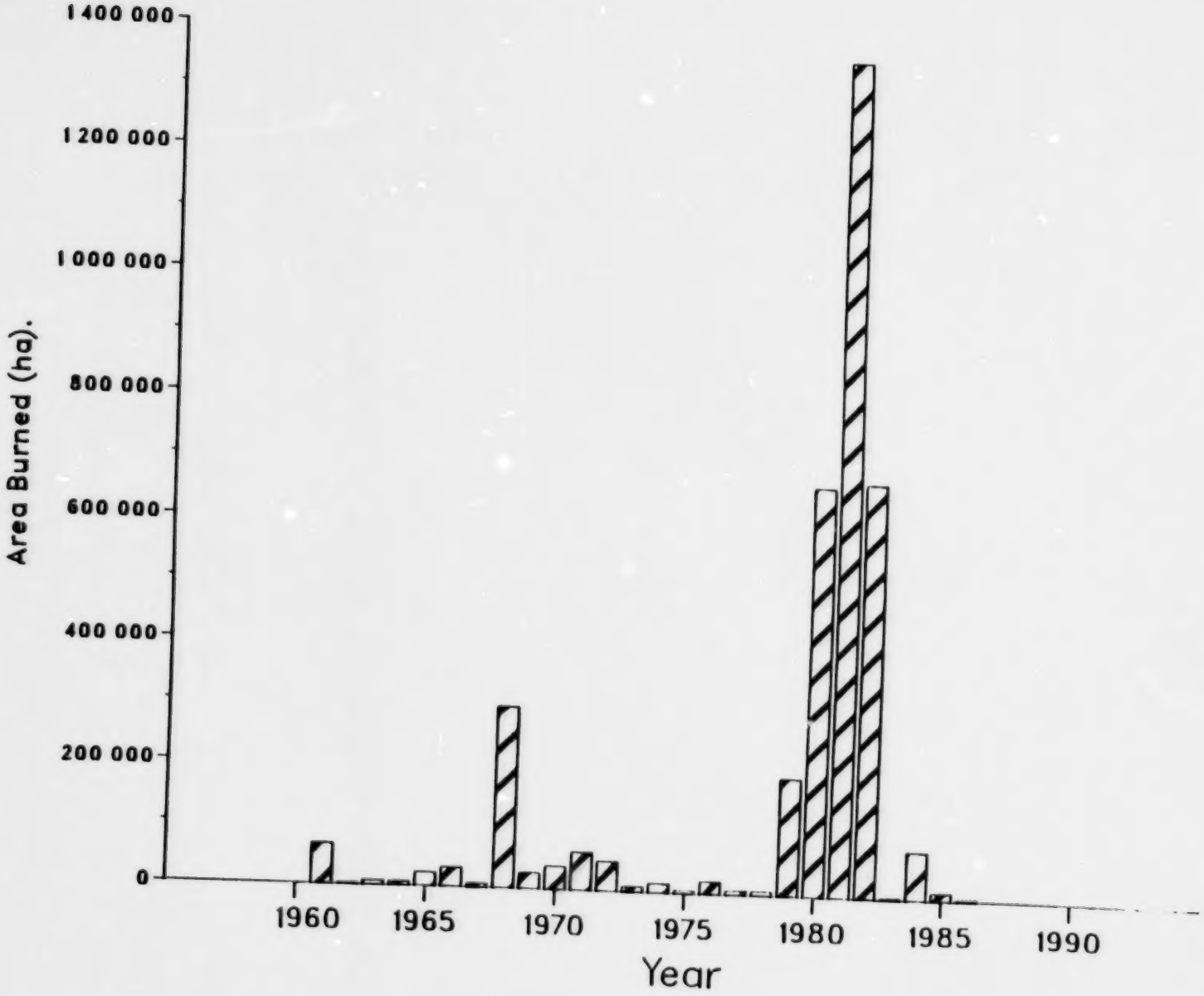

Figure 3: Burned area in the boreal region 1961 - 1986

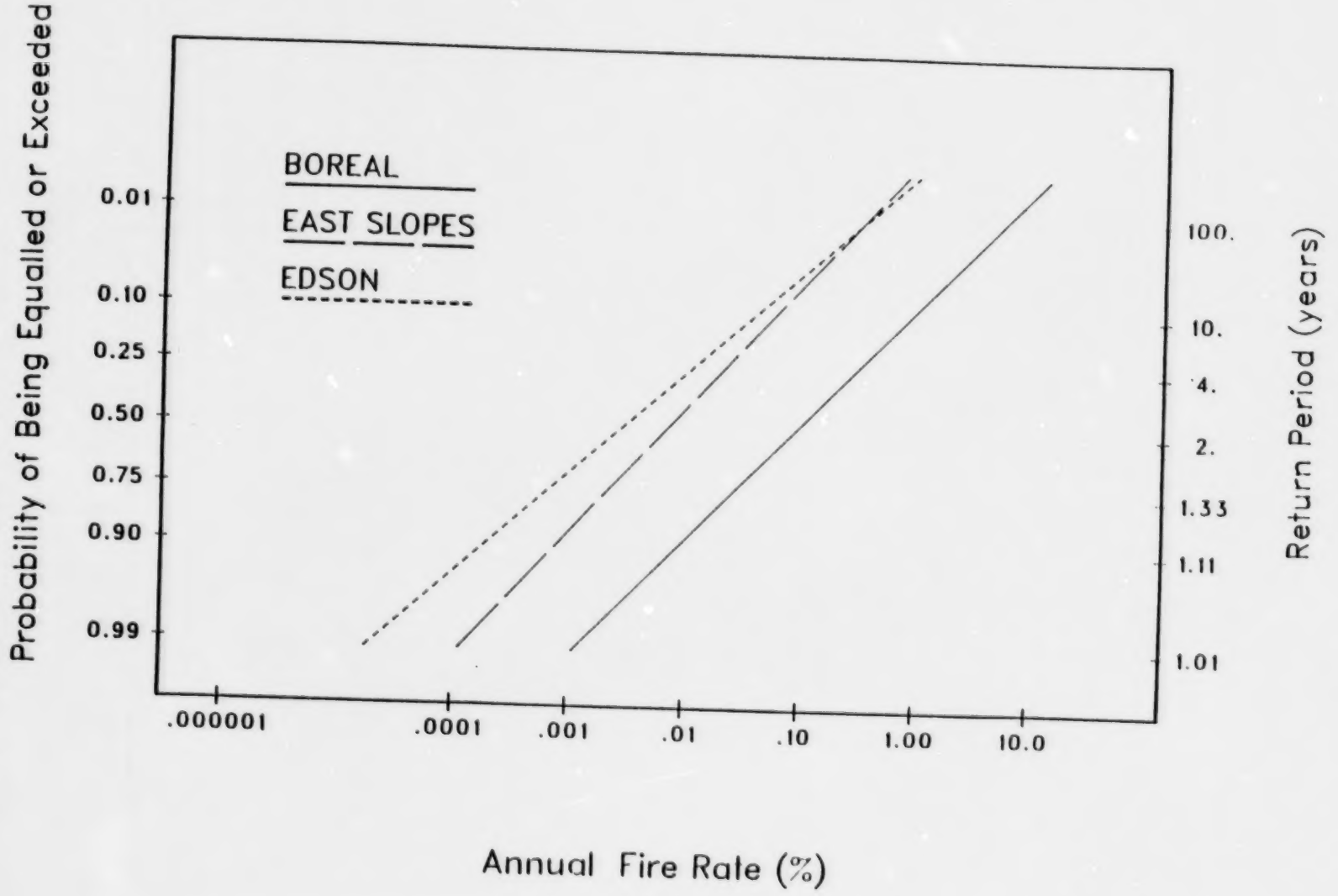

Figure 4: Fire frequencies for the East Slopes, boreal and Edson regions

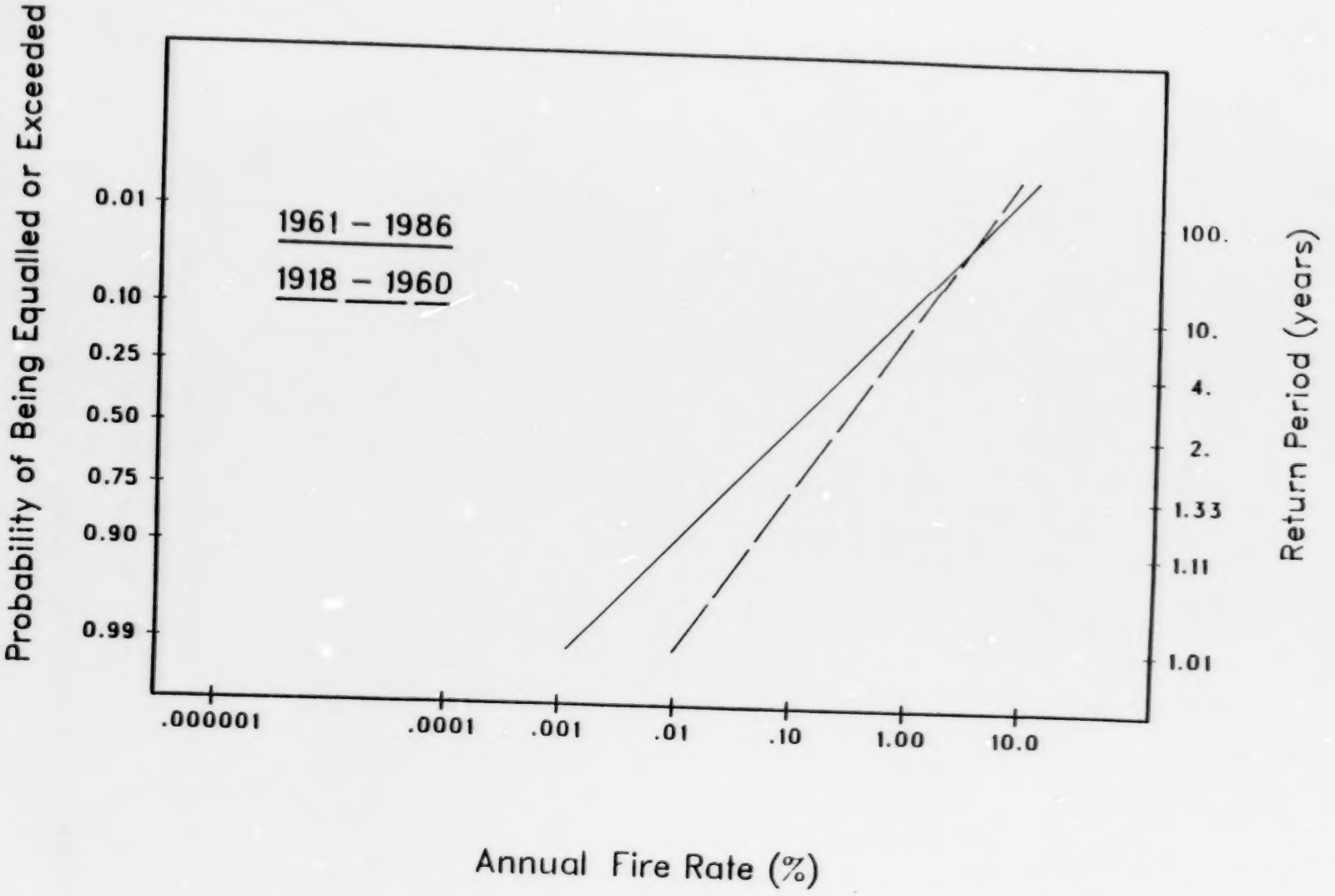

Figure 5: Fire frequencies for Alberta, 1918 - 1960 and 1961 - 1986

This distribution of cumulative probabilities of survival was determined for each of the two areas.

Figure 6 illustrates the distribution for the boreal area. The y-axis can be interpreted as the frequency of occurrence for particular cumulative probabilities of survival. As expected, most of the sequences are relatively mild, resulting in the skewed distribution. The variability in the distribution for the East Slopes was quite restricted, since fire rates in the historic record (1961 - 1986) are all relatively mild. Larger rates of fire may be anticipated in the future in light of the very large fires that have been found in fire history studies (e.g. Tande 1977, Hawkes 1979); evidence of very large fires is also present in age class distributions throughout the East Slopes. For example, the average fire rate determined from the age class distribution on the Forest Management Agreement (FMA) area of Champion Forest Products from 1850 - 1960 was 1.19%. The conclusion that the fire frequency curve for the East Slopes shown in Figure 4 will not represent anticipated fire behavior, does not invalidate the technique. However, it is clear that a longer period of record than 26 years is required to accurately estimate the parameters of the distribution. This should not be surprising since longer periods of record are generally required to establish climatic normals for mountainous regions (Powell and MacIver 1976) and the mean fire return interval in areas of high elevation is relatively large (e.g. Tande 1977, Hawkes 1979). The rates given in Table 1 for the East Slopes are the short-term average derived from the 1961 - 1986 fire records and the long-term average for 1850 - 1960 based on the age class data from Champion's FMA area. Given the discrepancy between the two rates, the increased level of protection and the long fire return intervals common in high elevation forests, future fire rates can probably be expected to lie somewhere between the two extremes.

Because the sequence of fire rates for the boreal area can show considerable variation as seen in Figure 6, three sequence severities were chosen to represent a broad range of possible events. The average annual fire rate required to produce the cumulative probability of survival was determined for three percentiles, 10, 50, and 90. The 10th, 50th, and 90th percentiles represented severe, moderate and mild fire sequences, respectively. Table 1 indicates the rates of fire used in harvest schedules for the McLeod Working Circle, based on both the East Slopes and boreal fire histories, as described above.

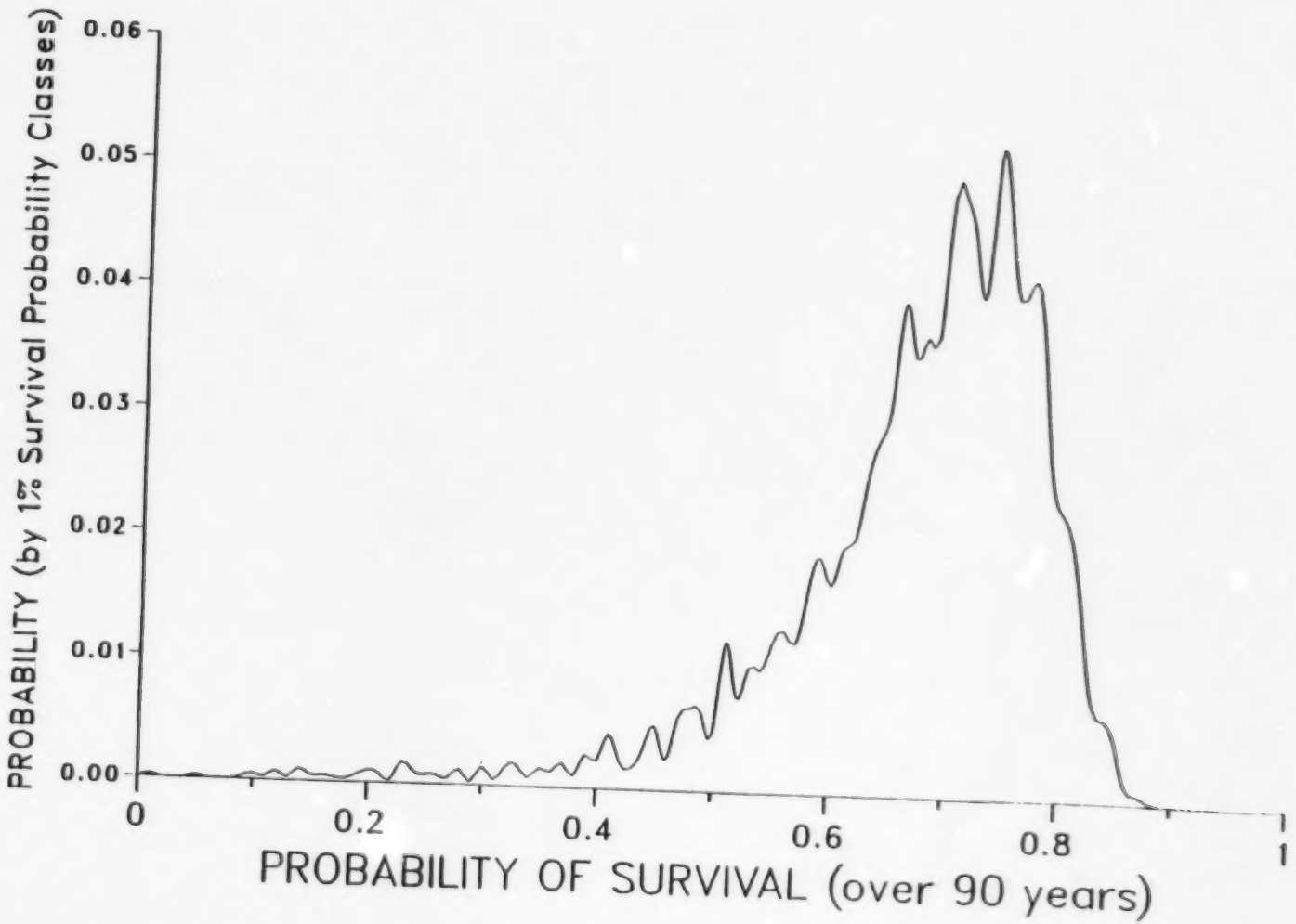

Figure 6: Cumulative probability of survival for the boreal region

Table 1: Summary of annual fire rates (%)

East Slopes:		
	1961 - 1986 average	0.03
	1850 - 1960 average	1.19
Boreal:	mild	0.26
	moderate	0.40
	severe	0.70

4. MODEL DESCRIPTION AND RESULTS

Champion Forest Products FMA area is divided into five sustained yield units called working circles. Each working circle is subdivided into compartments for the operational scheduling of harvests. The compartments are further subdivided in two sub-compartments, one for fire origin timber (standing timber) and one for timber regenerated after harvesting.

The harvest scheduling model currently used by Champion Forest Products is composed of two components, a yield projection system and a harvest scheduling system. The yield projection system is based on a grid of photo-points. Through a series of equations developed from the Company's permanent sample plot network, the volume and height of each photo-point are projected at regular intervals over time. These variables are aggregated to produce averages for each sub-compartment overtime. The aggregated yields are then used in a modified area-volume check (Chapelle and Sassaman 1968) to determine the harvest level required to completely harvest the forest in a specified time period.

The harvest scheduling model uses sub-compartments as its basic unit. Use of these operational based units is more realistic than units based on the aggregation of dispersed inventory classes which are common in other scheduling models. The harvest sequence of each sub-compartment is generally based on age with the oldest sub-compartment harvested first.

The model was modified for this study to incorporate probabilistic rates of destruction. Each photo-point was assigned an annual probability of destruction. Total annual loss probability (p) can be calculated by combining independent estimates of loss probabilities from individual sources. Thus:

$$p = 1 - (1 - p_f)(1 - p_i)$$

where: p_f = annual loss probability from fire

p_i = annual loss probability from insects

However, only losses from fire were judged sufficiently quantifiable to merit inclusion in the case study at this time. The cumulative probability of survival for various projected intervals was calculated as follows:

$$\text{Cumulative probability of survival at n years} = \prod_{i=1}^{n} (1 - p_i)$$

where: p = rate of destruction for year i

The cumulative probabilities of survival were aggregated on a sub-compartment basis and used in the harvest projection system.

The harvest projection system determines the year that harvesting commences and the time to cut for every sub-compartment. The cumulative probability of the sub-compartment surviving until harvest is based on the average length of time from the beginning of the harvest schedule to when

the stand is completely harvested. Thus every sub-compartment has a probability of survival or, more descriptively, a probability of realizing the deterministic projected volume. The expected volume to be harvested from any one subcompartment is determined by the multiplication of the projected volume by the probability of realization. The product of the volume weighted probability of realization for the entire harvest schedule and the deterministic AAC is the expected average annual harvest.

The model is not intended as a rigorous and comprehensive description of risk in timber management. It cannot be used to determine optimal harvest rates. However, the model is useful for indicating how the probability of realizing projected volume decreases over time and how rotation decisions affect expected volumes. The effect of changes in compartment sequencing can also be assessed. The probabilistic elements incorporated into the Champion model are applicable to other harvest scheduling models being applied elsewhere.

The research by Reed and Errico (1984) has indicated that rotation ages should be reduced in order to maximize productivity when the stand is subject to risk. Their technique for determining optimal rotation age was applied to an Alberta Forest Service yield curve for medium site lodgepole pine (Alberta Energy and Natural Resources, Forest Service 1985) for several fire rates. The purpose was to illustrate the range of rotation ages that can be expected if risk is considered. The fire rates chosen were simulated from a fire frequency curve based on provincial fire rates from 1961 to 1983. The mild, moderate and severe annual rates used were 0.25%, 0.38%, and 0.64%, respectively. The results are shown in Figure 7. The tangent of these curves which passes through the origin indicates culmination of mean annual increment. Rotation ages vary from approximately 80 to 100 years depending on the assumed fire rate.

In this study, the influence of the rotation decision on expected average annual harvest was tested using three rotations, 80, 90, and 100 years. The results are shown in Table 2. Two annual fire rates were tested for the East Slopes; one is the average based on short-term fire history (1961 - 1986) and the other is the average based on long-term fire history (1850 - 1960) derived from the age class distribution of Champion's FMA area. The boreal fire rates and the resulting expected annual yields illustrate the impact that fire would have on harvesting in a boreal forest of similar structure and productivity as the McLeod Working Circle.

The expected average annual yields produced by the harvest scheduling model under various assumptions of rotation and fire rates are shown in Table 2. Risk of destruction due to losses other than fire has not been included in these simulations. The simulated harvest schedules produced from the model are found in Appendix 1.

Figure 8 illustrates the results in terms of the reduction in expected annual harvest from the deterministic annual harvest assuming no fire. The expected reductions in annual harvest over relatively short planning horizons are dramatic. It is apparent that the benefit obtained by reducing rotation age for risk increases as the severity of fire increases. Although the rotation of 80 years produces the least reduction in expected annual harvest over the time spans indicated, it will not necessarily be the optimal rotation when long-term productivity is the objective. Optimal

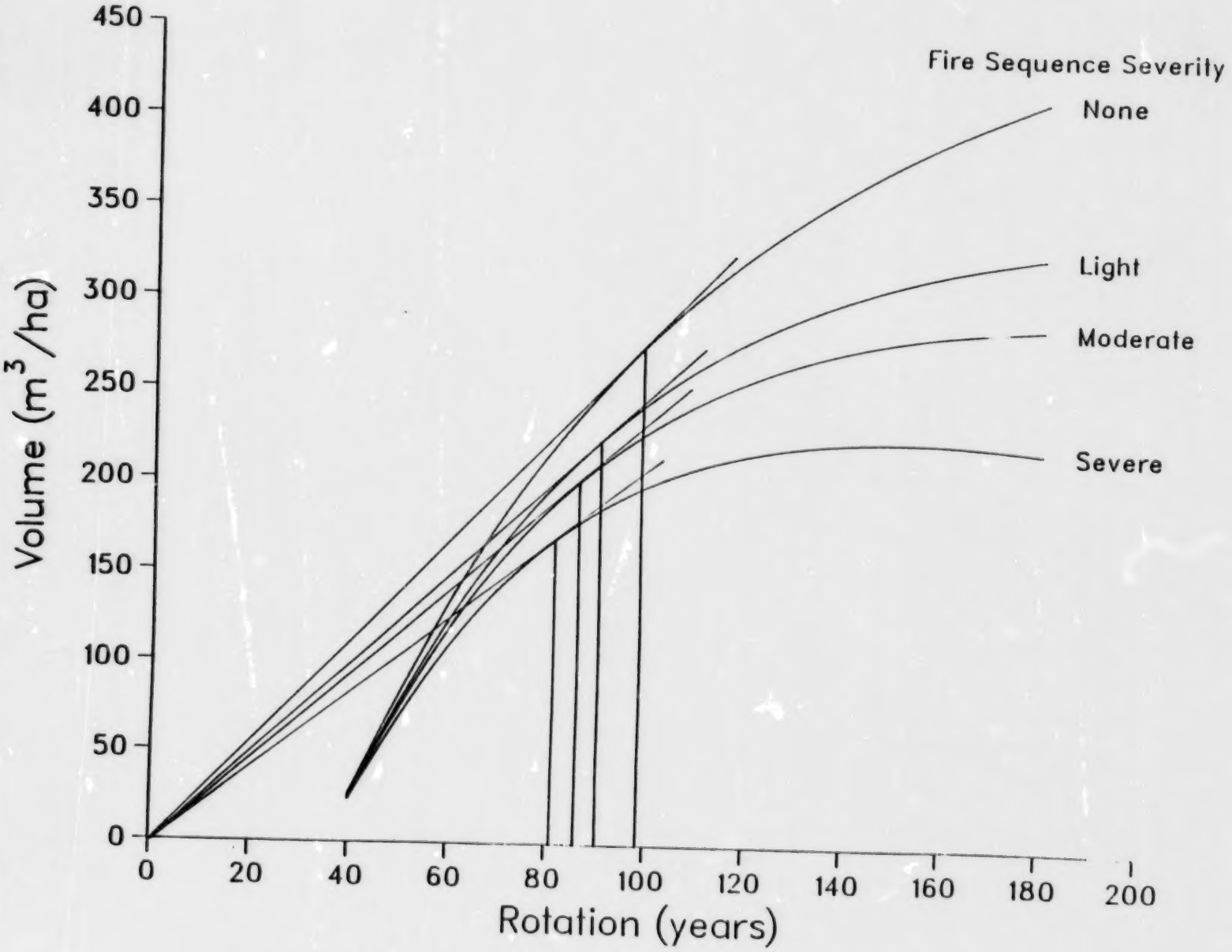

Figure 7: Volume-rotation curves for lodgepole pine in Alberta

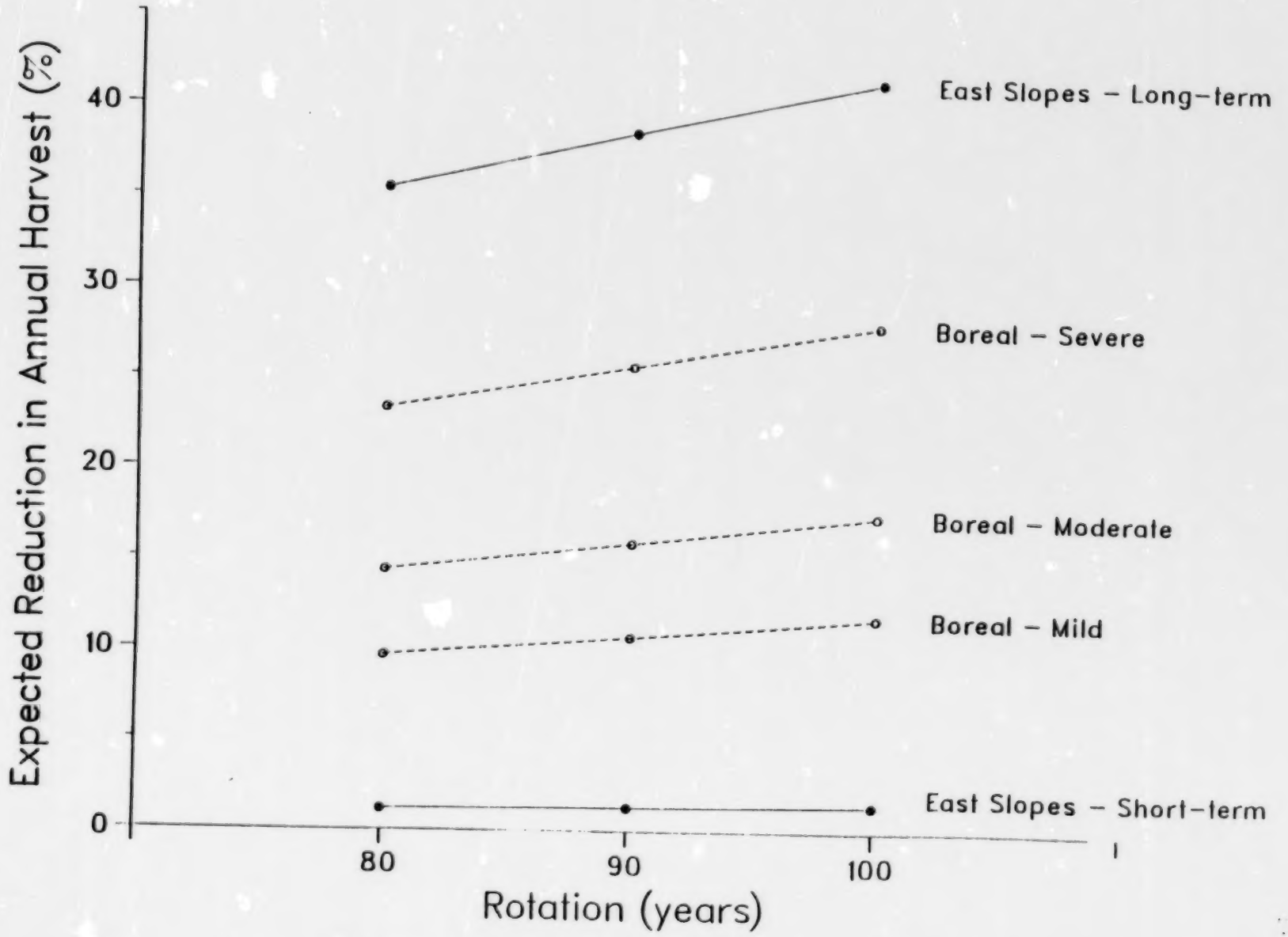

Figure 8: Expected reductions of average annual yields based on projected inventories for the McLeod Working Circle.

stand rotations must be determined through procedures such as those developed by Reed and Errico (1984).

The results shown in Figure 8 indicate that the expected harvest is highly dependent on the rate of fire. A relatively small reduction in fire rates will produce a large benefit in expected yield. It is apparent that the use of risk management techniques such as reducing rotation age improves expected harvest but that benefit is relatively small compared to the large potential benefit of a reduction in fire rates. This is not meant to imply that one approach is more important than the other, but rather that all methods of reducing the impact of risk on timber supply need to be considered.

Table 2: Expected average annual yields (in cubic metres) by rotation and fire severity

	Rotation (years)		
Fire Severity	80	90	100
None	400384	371655	346513
East Slopes Fire Rates			
Short-term Rate	395630	366706	341383
Long-term Rate	258167	228234	202549
Boreal Fire Rates			
Mild	361551	335519	305214
Moderate	342713	312295	285690
Severe	306613	275938	249264

5. RELATIONSHIP OF STAND ATTRIBUTES TO FIRE

Forests in Champion's FMA area are largely of fire origin. Under natural conditions, the age class distributions of such forests are a reflection of fire history. Several studies (Van Wagner 1978, Johnson and Van Wagner 1985) have used this relationship to derive models of fire history from age class information. For this study, no attempt was made to use statistical distributions to model past fire occurrences, but it was felt that stand age could be useful as a relative index of fire frequency.

Champion Forest Products maintains a system of approximately 3000 permanent sample plots (PSPs) which are systematically arranged in clusters of four. Every plot represents an equal area. Age, cover type, and other mensurational data are available for each plot. For every plot cluster, an elevation was assigned by reference to 1:50 000 scale maps of the National Topographic System series. The majority of the plots were established prior to commencement of harvesting. However, those plots that were placed after harvesting were excluded from the analyses reported here. Therefore, all plots used represent the natural fire origin forest.

The relationship of fire frequency to elevation has been reported by several researchers including Tande (1977), Johnson (1978), and Hawkes (1979). Figure 9 shows the relationship of mean age to elevation for Champion's FMA area. In general mean age increases with elevation which is consistent with the decrease in fire frequency with elevation found elsewhere. Fire frequency can be expected to be lower in high elevations due to generally increased precipitation, lower temperatures, and higher relative humidity. However, as seen in Figure 9, there is a relatively large elevation range from 900 m to 1300 m over which mean age does not vary appreciably.

To test the combined effect of elevation and cover type, an analysis of covariance was performed. Elevation was used as the covariate and cover type as the main effect. Both elevation and cover type were found to be statistically significant.* Given the significance of cover type, a range test was performed for this variable. The results are shown in Table 3. Interpretations are somewhat confounded because of the complex interaction between the causative factors of cover type (Van Wagner 1983b). For example, some of the differences may be due to the inherent flammability of the species while other differences may be due to their regeneration mechanisms. Based solely on this table, it is not possible to determine if the apparent relationships merely reflect fire history or in fact, influence fire history. However, inferences of fire frequency can be drawn from age class data provided that knowledge of fire behavior and of the regeneration mechanisms of the species are considered.

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* at the 0.05 level of probability

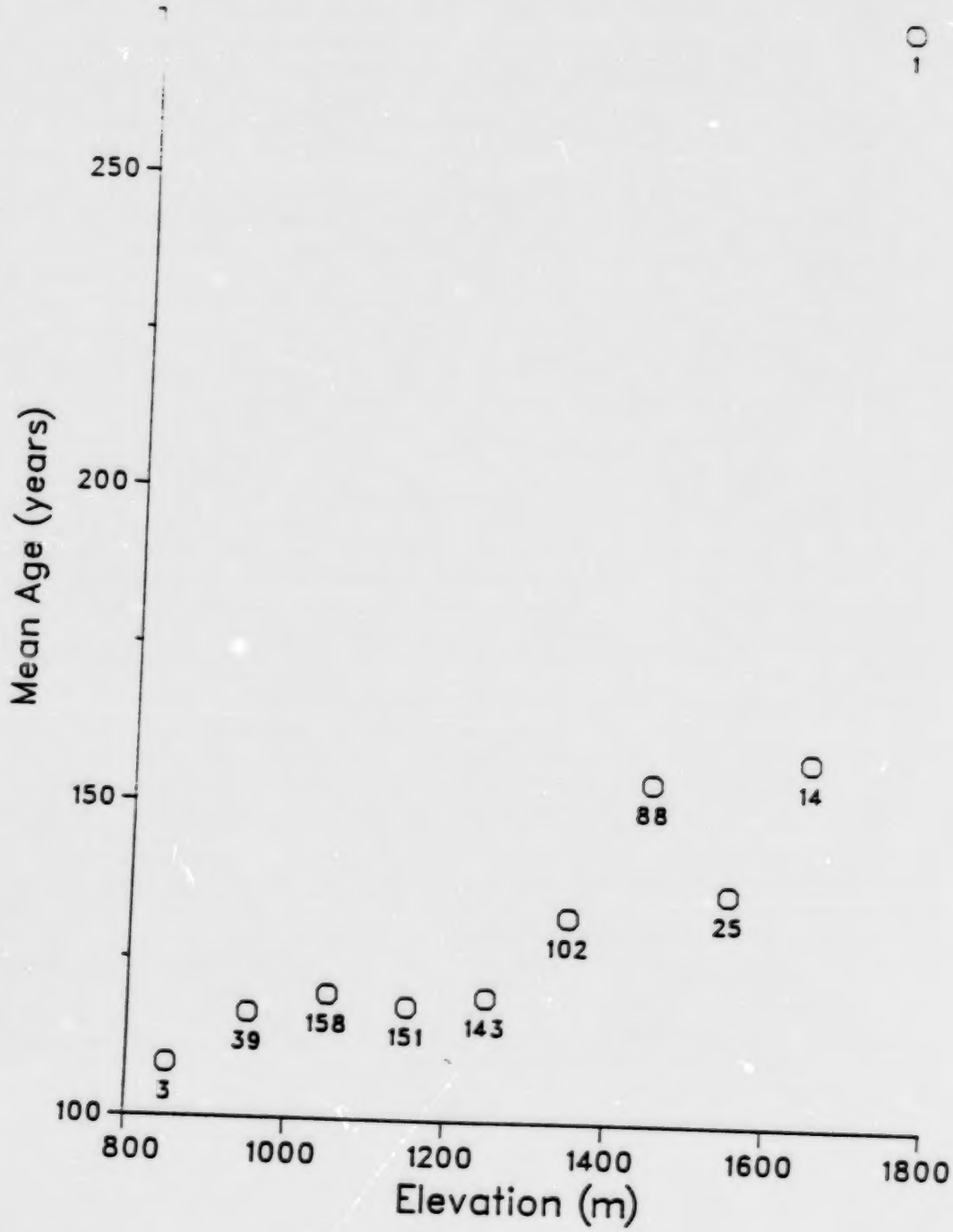

Figure 9: Mean age by elevation in the Champion forest management area (the numbers refer to the number of plot clusters within each elevation class)

Table 3: Cover type and age relationships

Cover Type Class	Mean Age	Range Test Results *
Pure Hardwoods	94.9	A
Hardwoods with Softwoods	98.3	A
Lodgepole Pine - Hardwoods	102.9	A
Pure Lodgepole Pine	105.3	A
White Spruce - Hardwoods	107.7	A
Pure Lodgepole Pine - Softwoods	128.8	B
Black Spruce - Others	146.7	CD
Pure White Spruce	155.3	DE
Pure Black Spruce	159.1	E
White Spruce - Softwoods	171.2	E
Subalpine Fir - Pure and Others	211.4	F

* Cover type classes with different letters have means which differ significantly as determined by the Student-Neuman-Keuls Multiple Range Test at the 0.05 level of probability.

6. GROUP CONSULTATION

Given the multidisciplinary nature of the study and the complexity of the issues involved, a meeting to coalesce ideas from different viewpoints was arranged. Preliminary results illustrating the modelling procedure and the locally-derived relationships of stand age with elevation and cover type were presented. The participants were divided into two groups with a mix of disciplines within each. A series of questions was posed to the participants. Each group discussed the questions separately, and then a spokesperson from each group presented the consensus of the group. This was followed by a general discussion. The questions and the results of the group consultation are contained in Appendix 2.

The major conclusions from this group consultation will be discussed here. The first was that the use of historic fire data in forecasting should be based on the stratification of regions with similar fire history. It was suggested that ecological regions could be used for such a stratification. Since accurate and relevant historic fire data are of relatively short duration, stratification must be kept broad. It was generally agreed that in regions in which the long term historic fire frequency differs substantially from recent fire history, longer periods of record may be required to obtain an accurate estimate of fire frequency. Because long fire records of sufficient detail do not exist, subjective interpretations of probable fire frequency may be required in regions where the average recurrence interval of severe fires is large. Thus methods used to estimate fire frequency may vary by ecological region.

Perhaps the most important idea produced from the group consultation was the concept of risk-adjusted harvest scheduling. More specifically, the group felt that it was possible to differentiate, at least to some extent, stands on the basis of potential fire danger, and agreed that the priority for harvesting stands should reflect this potential; even a very modest level of resolution was thought to be useful. The intent of priorizing stands with regard to fire danger is to reduce the probability of occurrence of severe fires. Quantitative methods for predicting the spread rate and intensity of surface fires, the potential for crowning and the spread rate for active crown fires are available (Van Wagner 1977, Lawson et al. 1985). Furthermore many of the required data are currently collected or could be collected in conjunction with existing timber inventories (refer to 8.2).

Policies regarding allowable cut and rotation age were also examined. It was concluded that allowable cuts should not be reduced in response to forecast risk and that there is some justification for reduced rotation age as shown by Reed and Errico (1984) and others.

When asked to identify the main causes of irregular mortality (i.e. mortality other than that resulting from intra-specific competition) and volume loss other than fire, likely to affect stands in the McLeod Working circle, the group concluded that mountain pine beetle (Dendroctonus ponderosae Hopk.) is less likely than fire to effect catastrophic losses, but is a concern as long as concentrations of timber over 80 years old exist. In second-rotation softwood stands, biotic damage by mammals, insects, and fungi was considered a high risk requiring urgent attention.

The anticipated damage in managed stands was thought to have management implications regarding stocking and density control.

7. SUBSEQUENT ANALYSES AND INVESTIGATIONS

7.1 FIRE

The cost associated with priorizing compartments on the basis of fire danger was assessed by determining the change in AAC resulting from a subjective priorization of compartments. In consultation with the Chief Forester of Champion Forest Products and the Senior Instructor for Fire Control with the Forest Technology School, several compartments were identified as having a high priority for harvesting. Since quantitative data regarding fuels was unavailable, the priorization largely reflected geographic location and values at risk. One of the compartments (XII) with a high priority adjoins a major transportation corridor and as a result has a high incidence of fire starts (see Figure 10). Furthermore, under dry conditions, fire in this low elevation mixed-wood compartment could easily spread south-east into a large area of mature coniferous forest. Compartments XXI and XXV were also identified as having a high priority for removal since large areas of uniform continuous forest cover lie to the east in the Embarras Working circle* and the prevailing wind is westerly. Compartments XIII and XIV may also be relatively important to remove because they are of low elevation and near areas of high fire incidence.

These changes in harvesting priority from the "oldest first" strategy do not reflect all of the changes that would be likely if quantitative methods of analyses were applied. However, the new harvest schedule can be used to demonstrate the influence of this management technique on projected harvests. The deterministic AAC was reduced approximately 1.12% with the altered harvesting priority. The question of whether the cost in terms of additional planning and reduced AAC is worth the benefit of a reduction in the probability of severe fires is difficult to answer categorically. Relatively detailed and rigorous models have been used to assess the benefit associated with fuel manipulation (Hirsch et al. 1981). The need for quantification of the benefit will depend, in part, on the cost of the altered schedule. Judging from the low reduction in AAC in this simple example, and the magnitude of predicted losses (refer to Table 2), quantification of the change in expected area burned may not be necessary. In addition, such quantification would require the estimation of the probability of severe fire conditions, which would be quite difficult to establish.

7.2 BIOTIC DAMAGE

In response to the concerns, raised through group consultation, experts and literature were consulted regarding the potential impact of known pathogens in the McLeod Working Circle, and in the East Slopes as a whole.

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* The Embarras Working Circle is south-east of the McLeod (refer to Index Map on Figure 10).

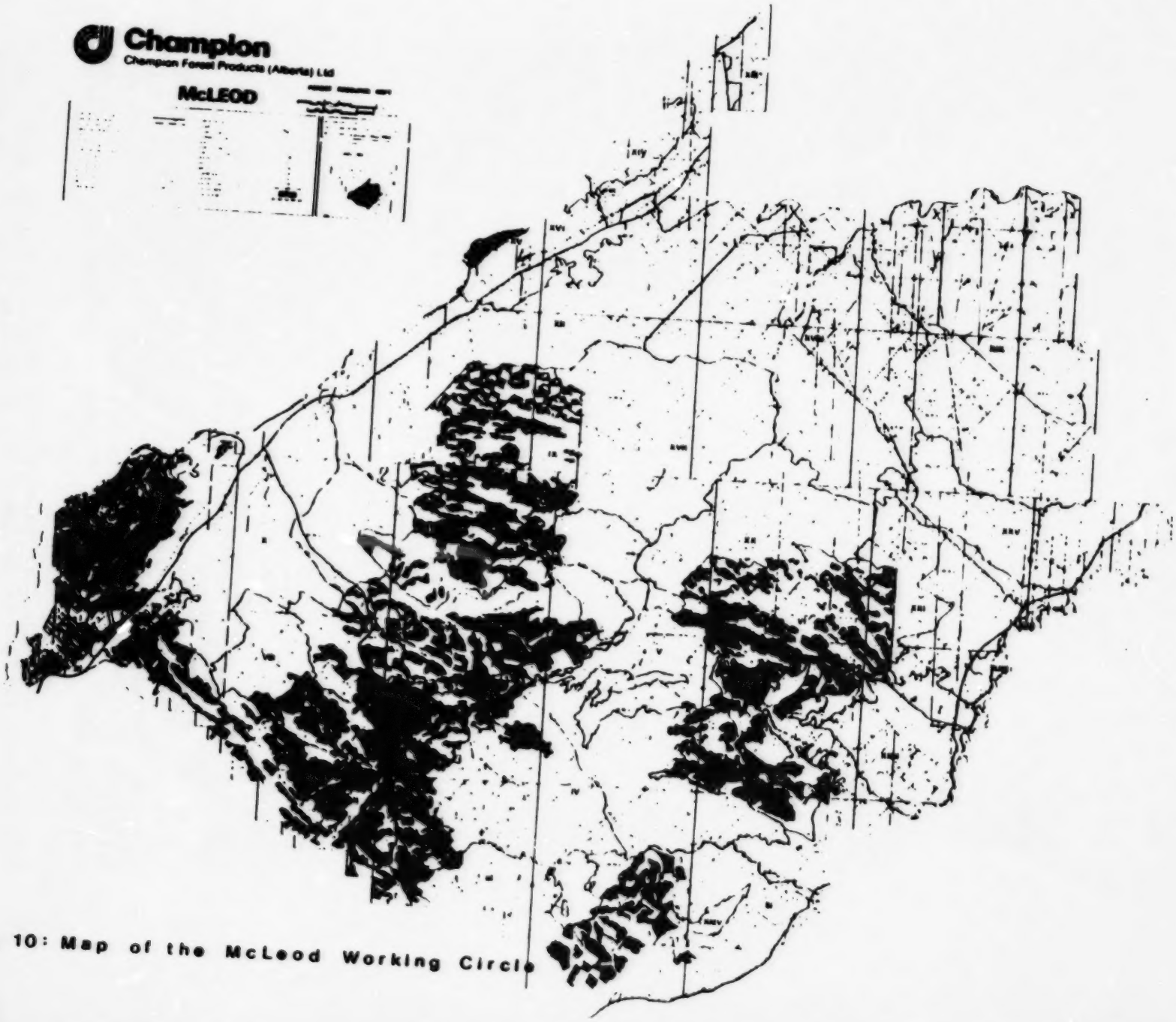

Figure 10: Map of the McLeod Working Circle

7.2.1 Mountain Pine Beetle

Although the mountain pine beetle has been detected in Alberta's forests in the past, the most recent outbreak beginning in 1977 was the first significant infestation to threaten major forest stands along the East Slopes (Alberta 1986). The epidemic was contained as a result of climatic conditions, the natural forest/prairie boundary, and the treatment activities.

The dynamics of infestations are affected by a number of factors including ambient temperatures and the age and size of timber available. Brood productivity increases with tree size in excess of 20 cm diameter and decreases with stand density. Susceptibility increases dramatically with age in trees over about 80 years old. Hazard of outbreak decreases with elevation. The Champion FMA area has been rated at low to very low hazard, as were areas attacked in the 1977 outbreak in southern Alberta (Sufranyik et al. 1982).

The McLeod Working Circle has an age-class distribution fairly typical of the East Slopes, with the exception that the orderly removal of over-mature timber is more advanced than in many other areas. Yet projections conducted as part of this study indicate that largely because of the concentration of lodgepole pine originating from huge fires about 97 years ago, the average age of timber harvested will continue to increase for another 50 to 60 years, and at no point over the next rotation will the average harvesting age drop below 80 years (see Appendix 1). It is probable that other areas in the Eastern Slopes are in a similar or worse position regarding the retention of increasingly susceptible timber, if managed on an even-flow basis. Forest harvesting will obviously reduce amounts of susceptible timber relative to those which would exist without harvesting, but there may be little justification for assuming that harvesting will reduce hazard progressively over time, at least within the foreseeable future. Over the planning horizons used in provincial forest management planning, uncertainty over outbreak hazard is increased by the observed trend towards increasing temperature and precipitation in the boreal region of western Canada (Singh and Powell 1986).

7.2.2 Biotic Damage to Second-rotation Stands

A number of insects and fungi which can cause death or reduce yields of conifers are know to be endemic in the McLeod Working Circle and surrounding areas (personal communication, H. Cereske, February 23, 1987). These include Warren's root collar weevil (*Hylobius warrenii*), terminal weevils (*Pissodes terminalis* and *Pissodes strobi*), pitch nodule moths (*Petrova* spp.), spruce bud midge (*Rhubophaga swainei*), *Armillaria* root rot, rust fungi (*Cronartium* spp. and *Endocromartium harknessii*), *Atropellis* canker, and *Fomes pini*. Other influences which should be considered in risk assessment include dwarf mistletoe, snowshoe hares, other rodents, hail, wind, and red-belt. The incidence and effects of these pathogens are well documented (e.g. Baranyay and Stevenson 1964, Cereske 1974, Bella 1985), but effects have not generally been sufficiently quantified for incorporation into stand and forest-level yield projections.

If such organisms have the same impact on future growth and mortality as they have in the past, and if stocking levels in regenerated

stands are sufficient to offset mortality, it may be assumed that their impact is incorporated into yield tables used in timber supply forecasting. However, there is somewhat alarming evidence that neither of these assumptions may be valid in boreal forest management.

Bella (1985) demonstrated that thinned stands of young lodgepole pine in west-central Alberta had a higher incidence of attack by common pest organisms than did non-thinned stands. Although elsewhere methods have been developed for estimating the impact of insects on volume growth and yield (Hainze and Benjamin 1986, Brace 1971), no such techniques have been applied to yield forecasting in Alberta.

W.G.H. Ives (personal communication, March 19, 1987) established study plots during 1981 and 1982 in 60 stands of lodgepole pine throughout the Champion Forest Management Area, ranging in ages from about 10 to 25 years. Incidence of damage and mortality have been assessed each year since. Annual mortality rates have averaged over one percent. There is as yet no clear indication that mortality decreases with age, in fact the highest mortality occurred in the oldest age classes. The most important pathogens causing mortality appear to be snowshoe hare, Armillaria root rot, Hylobius warrenii, and Endocromartium harknessii. Mortality levels observed by Ives, if sustained at uniform rates for 30 years, would result in about a 30 percent reduction in number of live trees. This observation is based on the formula:

$$\text{Cumulative probability of survival at n years} = (1 - p)^{n}$$

where: p = annual mortality rate.

Sustention over an entire 90 year rotation would result in a loss of over 60 percent. In fire origin stands, or even in logged stands which have regenerated prolifically and been left unthinned, this mortality may be beneficial rather than detrimental. Implications are more serious to plantations or regenerated stands stocked only to mandatory provincial standards, and to precommercial thinning regimes. Most stocking standards, including legislated minimum standards applied in Alberta, assume little or no mortality between crop establishment and semi-maturity (Bella 1978, Alberta Energy and Natural Resources 1979).

Uncontrolled vegetative competition gives rise to similar concerns. J.C. Wright (personal communication, March 16, 1987) stressed the significance of poplar competition on the survival and growth of pine and spruce. This competition will continue to impact on regeneration from five years after logging until the poplar overstory starts to break up at approximately 100 years of age. Wright pointed out that the provincial practice of assuming full stocking and normal coniferous growth rates for such stands is unrealistic, unless effective and economical means of controlling competition are available.

8. DISCUSSION AND CONCLUSIONS

The results of this and previous studies indicate that the risk of destruction and the risk associated with stand growth have very serious implications for timber supply. However, quantitative determination of the level of risk is difficult. But as Clutter et al. (1983) suggest:

> "... the fact that a concept is difficult is not sufficient grounds to ignore it. The ultimate test is: 'Does the use of these procedures result in better decisions?' If this query can be positively answered, then procedures to account for risk merit consideration."

In light of the severe consequences of risk that have been demonstrated, three areas of management have been identified which require consideration:

1. Accepted approaches for dealing with uncertainty and risk, applicable to current forest management techniques.

2. Principles of fire, insect and disease management which can be integrated with overall forest management on an operational level to reduce the level of risk present.

3. Incorporation of risks associated with loss due to fire or other destructive agents into investment decisions.

8.1 THE APPLICATION OF RISK MANAGEMENT PRINCIPLES TO FOREST MANAGEMENT

Under conditions of uncertainty, the importance of the "distant future" in current management decisions should be reduced (Weintraub 1976). In timber management, analytical and simulation methods for calculating harvest levels have been developed (Navon 1971, Johnson and Jones 1980, Chapelle and Sassaman 1968), and are being applied throughout Canada. In many of these formulations the current harvest rate is constrained by the long-term harvest rate projected some two to three hundred years into the future. The uncertainty associated with that long-term rate is very high. The projected management activities are assumed to be carried out as planned, the forest is assumed to grow as predicted, land base is assumed to be constant, legislative constraints are assumed to remain unchanged, and catastrophic and irregular mortality are frequently assumed to be non-existent. Basing the current harvest on this long-term rate is poor risk management, and cannot be improved simply by the application of a deterministic loss factor.

If the long-term harvest rate includes projections for loss such as Reed and Errico's model (1985), there is still no rational basis to constraint harvest rates to long-term supply. Destruction by fire, insects or disease is stochastic. Severe losses may occur next year or they may not occur for 200 years. Projection of losses which are highly unpredictable does not remedy the problem associated with constraining current harvest rates to the distant future. If constrained optimization approaches are used in harvest scheduling, the constraints must be very flexible and/or the planning horizon should be relatively short.

Another risk management technique is frequent replanning; it is particularly appropriate for dealing with highly unpredictable elements (Fight and Bell 1977, Lembersky and Johnson 1975, Stevens 1986). Forest management agencies in Canada generally follow this policy. Inventories are updated at relatively short periodic intervals to reflect changes in forest structure resulting from unpredictable losses and/or changes in management activities. However, the failure of management agencies to acknowledge the role of replanning in dealing with risk can lead to highly questionable decisions, such as the common policy of reducing AAC for anticipated fire, insect and disease losses which five provinces currently follow (Stevens 1986).

8.2 INTEGRATION OF MANAGEMENT TECHNIQUES ON AN OPERATIONAL LEVEL

Destructive agents in forestry are generally unpredictable. However, it is expected that these catastrophic and irregular losses will occur at some time in the future. Given the serious effects of such losses, it is prudent to attempt to reduce the severity of such losses or conversely reduce their probability of occurrence through management. This does occur now, but protection measures are usually not well integrated with overall land management. In particular, there appears to be considerable opportunity for forest harvesting to manipulate fuels to reduce the probability of severe fires. This has been demonstrated in the literature (Fahnestock 1979, Chandler et al. 1983), and would appear to apply in the McLeod Working Circle case study.

For logistical reasons, harvesting operations are generally planned so that operations at any one time occur within a relatively small group of stands. The design of these compartments and the order in which they are currently harvested reflects only timber management considerations (Clutter et al. 1983). However, the design and harvest priority of the compartments should also consider fire behavior principles.

Considerable research effort has been placed on modelling fire behavior. The application of this knowledge to harvest scheduling would be an excellent opportunity to integrate fire and timber management. As this study has demonstrated the cost of these procedures in terms of AAC is likely to be small and the benefit potentially very large.

Fuel measurement and appraisal are basic to the concept of fuel manipulation and a great deal of information is available on these subjects. The ability to predict the accumulated downed woody fuels is poor (Fahnestock 1979, Brown and Johnson 1981). The problem is that stand history is generally more indicative of surface fuels than current stand attributes. However, simple methods of inventorying the surface fuels do exist (Brown 1974, Van Wagner 1968) and the measurement time per plot is small (Brown and Johnson 1982). Collection of this information could be coordinated with other forest inventories.

The capability to predict crown fuels is good. Van Wagner (1977) identified three important crown fuel properties: height above ground, foliar bulk density and foliar moisture content. Folian bulk density can be estimated from weight of crown foliage, and number of stems per hectare by diameter class. Relationships predicting crown foliage weight from diameter at breast height (dbh) for various coniferous species have been developed

(Brown et al. 1977). The distribution of stems by diameter class is available from standard forest inventories.

The relative fire behavior potential could be determined from the consideration of the following variables (Alexander 1987):

a. The rate of spread and intensity for surface fires using the Canadian Forest Fire Behavior Prediction System (Lawson et al. 1985);

b. The potential for crowning (Van Wagner 1977);

c. The potential spread rate for active crown fire (Van Wagner 1977).

The potential fire behavior should be interpreted by fire managers and timber managers in relation to risk of incidence, geographic location, and values at risk. The priority for harvesting can be established with the aim of reducing the probability of severe fires.

The potential for fuel manipulation is greatest in areas where the differences in potential fire behavior are pronounced, such as the East Slopes. But in areas of high fire risk, such as the boreal forest, the importance associated with hazard reduction is magnified. Relatively expensive measures of protection, such as fuelbreaks, may merit investigation in these areas.

8.3 CONSIDERATION OF RISK IN INVESTMENT DECISIONS

The explicit consideration of risk in business decision-making is hardly novel. In fact, the science of operations research has developed to aid managers with such decisions. However, very little explicit recognition of risk occurs in timber management. Yet this study and others indicate that risk associated with destructive agents and growth is likely to have a major influence on future timber supply.

Deterministic approaches to investment in forestry are typical. Silvicultural investments are rationalized on the basis of present net value neglecting the large risk associated with such long-term investments. Investments which depend on timber supply must also consider the risk associated with reductions in that supply. Despite the "sustained yield" philosophy of foresters, timber supply in the short-term cannot be assured when the potential magnitude of loss from fire, insects, disease and vegetative competition is high.

A common method of adjustment for risk in investment decisions is to determine the expected value of the investment when realized and then discount it back to the present using valuation procedures (Foster 1979, Chang 1980). Another method proposed by Foster (1979) is to add a premium equal to the annual probability of risk to the discount rate.

With either method, the problem of quantifying the probability associated with particular outcomes still remains. The choice of the probability can reflect the investors attitude toward risk. For example, an optimist might feel that the effectiveness of fire protection will increase

in the future and therefore choose a rate of risk lower than the current average. This does not imply that quantitative analysis of risk is unnecessary, but rather that investors may choose to adjust a quantitative rate to reflect their attitude.

The use of expected values and probability distributions reflecting various outcomes to judge investment decisions is not unrealistic. In fact, it is the failure to incorporate risk into decision-making which is unrealistic.

Since risk of destruction by fire, insects and disease varies regionally, it is logical to stratify on a regional basis. Investigation of the stratification of risk on an ecoregion basis throughout the boreal forests of Canada would seem to be starting point.

8.4 SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

1. In the forests of Alberta, probabilistic destruction of timber through fire and biotic damage significantly affects expected long-term timber supplies.

2. Expected volume losses are affected by rotation length. If maximization of long-term productivity is desired, rotations based on culmination of mean annual increment should be reduced under conditions of risk or uncertainty.

3. Risk of destruction in the East Slopes is related to stand and location parameters including species composition and elevation. Therefore expected volume losses can be influenced by the sequence in which stands are harvested.

4. Rational allocation and management of timber resources in Alberta forests is affected by risk of destruction.

5. Current planning should not rely heavily on "distant" projections which contain a high degree of uncertainty. For example, the incorporation into allowable-cut decisions of optimistic assumptions regarding the yields of future regenerated stands has little rational basis in northern forests. A better approach to timber supply forecasting is the pragmatic scheduling of existing stands over a reasonable conversion period, with frequent replanning.

6. The cost of ensuring an even-flow of timber harvests is likely to be very high in northern forests because of risk. Harvesting at "safe" sustainable levels will result in large and immediate reductions in allowable-cut, and the accumulation and ultimate loss of growing stock. In view of the inevitable wastage and increased risk associated with reserving timber supplies, managers consulted in this investigation concluded that annual allowable cuts should not be reduced in response to risk.

7. In areas under industrial forest management, considerable potential exists for reducing the probability of fire and other catastrophic losses at little cost. Efforts to reduce risk must be coordinated with other management activities. In particular, harvest scheduling should

reflect differences between locations in potential fire and pathogen behavior.

8. An improved basis is required at the management unit level for risk-adjusted harvest sequencing. This is achievable through the development and incorporation of information on hazard changes into operational harvest-scheduling models. Here the quantitative reporting of long-term harvest reductions, as attempted in the case study, may be of less importance than incorporating any information the manager can acquire for projecting potential fire and pathogen behaviour.

9. In northern forestry, at the broader regional level, a higher emphasis should be placed on the concept of expected value. This is particularly important to investment decisions regarding facility development and discretionary silvicultural inputs in areas subject to significant risks of timber loss. Quantification of risk is required for rational risk management and investment decisions. A useful starting point would be the collation of available risk data on an ecoregion basis, using techniques as described and applied in this study. Regional collation of risk data is a necessary input to a number of other strategic decisions, such as the adjustment of harvest schedules to reduce risk.

10. Quantitative studies of biotic damage to regenerated stands, started by the Northern Forestry Centre, should be continued, extended to other stand types, and rigorously analyzed. Measurements should be extended to the collection of mensurational data necessary for growth modelling.

11. Foresters involved in long-term planning could benefit greatly from improved training and awareness in risk-management principles.

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Appendix 1: Harvest Schedules

SHORT-TERM EAST SLOPES FIRE RATE - 80 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.45	595508	1.5	1.5	0.9998
2	1986	950	119	206.14	195997	0.5	2.0	0.9995
3	1986	4541	116	212.60	965617	2 4	4.4	0.9990
4	1989	5945	117	246.92	1467929	3.7	8.1	0.9981
5	1993	972	117	171.04	166263	0.4	8.5	0.9975
6	1993	3980	116	212.46	845798	2.1	10.6	0.9971
7	1995	4431	116	217.41	963533	2.4	13.0	0.9965
8	1997	7511	116	209.46	1573329	3.9	16.9	0.9955
9	2001	1754	117	146.77	257532	0.6	17.6	0.9948
10	2002	7543	119	236.34	1782856	4.5	22.0	0.9941
11	2007	1902	121	216.05	410917	1.0	23.0	0.9933
12	2008	5167	120	236.84	1223846	3.1	26.1	0.9927
13	2011	7114	120	219.43	1561198	3.9	30.0	0.9916
14	2014	5907	123	229.42	1355184	3.4	33.4	0.9905
15	2018	5198	121	247.53	1286902	3.2	36.6	0.9896
16	2021	9585	124	221.52	2123408	5.3	41.9	0.9883
17	2026	6869	122	217.40	1493390	3.7	45.6	0.9870
18	2030	4632	124	123.78	573376	1.4	47.1	0.9862
19	2032	692	125	278.59	192840	0.5	47.5	0.9859
20	2032	10557	125	241.54	2550006	6.4	53.9	0.9849
21	2038	10022	129	220.39	2208833	5.5	59.4	0.9832
22	2044	215	124	90.79	19555	0.0	59.5	0.9823
23	2044	211	121	196.88	41600	0.1	59.6	0.9823
24	2044	13029	99	213.09	2776387	6.9	66.5	0.9813
25	2051	230	95	147.53	33961	0.1	66.6	0.9802
26	2051	4801	88	178.05	854876	2.1	68.7	0.9799
27	2053	7693	89	171.22	1317306	3.3	72.0	0.9791
28	2057	118	87	174.84	20788	0.1	72.1	0.9786
29	2057	5697	87	182.84	1041715	2.6	74.7	0.9782
30	2059	7961	89	189.19	1506290	3.8	78.4	0.9773
31	2063	2150	86	178.44	383702	1.0	79.4	0.9766
32	2064	1160	87	163.24	189441	0.5	79.9	0 9764
TOTALS		151945			31979896	79.9		0.9881

A constant cut of 400384. cu.m. is maintained for 79.9 years.

The expected volume is 395630. cu.m. for a average fire sequence severity.

SHORT-TERM EAST SLOPES FIRE RATE - 90 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.51	595690	1.6	1.6	0.9998
2	1986	950	119	206.25	196105	0.5	2.1	0.9994
3	1987	4541	116	212.92	967059	2.6	4.7	0.9990
4	1989	5945	117	247.72	1472706	4.0	8.7	0 9980
5	1993	972	118	172.37	167560	0.5	9.1	0.9973
6	1994	3980	116	213.36	849382	2.3	11.4	0.9969
7	1996	4431	117	218.76	969537	2.6	14.0	0.9962
8	1999	7511	117	211.42	1587989	4.3	18.3	0.9952
9	2003	1754	119	147.21	258302	0.7	19.0	0.9944
10	2004	7543	121	238.53	1799396	4.8	23.8	0.9936
11	2008	1902	123	218.55	415681	1.1	25.0	0.9927
12	2009	5167	122	239.80	1239186	3.3	28.3	0.9920
13	2013	7114	123	222.66	1584141	4.3	32.6	0.9909
14	2017	5907	126	233.17	1377382	3.7	36.3	0.9897
15	2021	5198	124	253.50	1317912	3.5	39.8	0.9887
16	2024	9585	127	227.66	2182315	5.9	45.7	0.9873
17	2030	6869	126	222.65	1529404	4.1	49.8	0.9858
18	2034	4632	129	128.31	594349	1.6	51.4	0.9849
19	2036	692	129	286.08	198023	0.5	51.9	0.9846
20	2036	10557	130	248.43	2622735	7.1	59.0	0.9835
21	2043	10022	135	226.44	2269473	6.1	65.1	0.9816
22	2050	215	130	93.45	20129	0.1	65.2	0.9807
23	2050	211	126	202.45	42778	0.1	65 3	0.9806
24	2050	13029	105	227.05	2958256	8.0	73.2	0.9795
25	2058	230	102	168.16	38709	0.1	73.3	0.9783
26	2058	4801	95	198.64	953716	2.6	75.9	0.9779
27	2060	7693	96	201.72	1551524	4.2	80.1	0.9769
28	2065	118	95	199.84	23761	0.1	80.1	0.9763
29	2065	5697	96	207.37	1181475	3.2	83.3	0.9758
30	2068	7961	98	213.64	1700925	4.6	87.9	0.9747
31	2072	2150	96	204.97	440742	1.2	89.1	0.9738
32	2074	1160	96	187.27	217330	0.6	89.7	0.9735
TOTALS		151945			33324088	89.7		0.9867

A constant cut of 371655. cu.m. is maintained for 89.7 years.

The expected volume is 366706. cu.m. for a average fire sequence severity.

SHORT-TERM EAST SLOPES FIRE RATE - 100 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.56	595874	1.7	1.7	0.9997
2	1986	950	119	206.37	196214	0.6	2.3	0.9994
3	1987	4541	117	213.24	968518	2.8	5.1	0.9989
4	1990	5945	118	248.54	1477550	4.3	9.3	0.9978
5	1994	972	118	173.72	168877	0.5	9.8	0.9971
6	1994	3980	117	214.17	852607	2.5	12.3	0.9967
7	1997	4431	118	220.14	975638	2.8	15.1	0.9959
8	2000	7511	119	213.40	1602914	4.6	19.7	0.9948
9	2004	1754	120	147.65	259079	0.7	20.5	0.9940
10	2005	7543	122	240.71	1815782	5.2	25.7	0.9931
11	2010	1902	125	221.11	420546	1 2	26.9	0.9921
12	2011	5167	124	242.84	1254868	3.6	30.6	0.9914
13	2015	7114	125	225.53	1604546	4.6	35.2	0.9902
14	2020	5907	128	237.02	1400086	4.0	39.2	0.9889
15	2024	5198	127	258.95	1346233	3.9	43.1	0.9877
16	2028	9585	131	233.69	2240081	6.5	49.6	0.9862
17	2034	6869	130	227.67	1563878	4.5	54.1	0.9846
18	2039	4632	133	132.46	613592	1.8	55.9	0.9836
19	2040	692	134	292.87	202726	0.6	56.4	0.9833
20	2041	10557	135	255.40	2696391	7.8	64.2	0.9821
21	2049	10022	140	231.29	2318107	6.7	70.9	0.9799
22	2055	215	135	96.09	20697	0.1	71.0	0.9789
23	2055	211	132	207.84	43917	0.1	71.1	0.9789
24	2056	13029	112	239.35	3118616	9.0	80.1	0.9776
25	2065	230	109	189.06	43521	0.1	80.2	0.9762
26	2065	4801	102	218.37	1048451	3.0	83.3	0.9758
27	2068	7693	104	231.86	1783863	5.1	88.4	0.9746
28	2073	118	103	222.22	26421	0.1	88.5	0.9738
29	2073	5697	104	229.67	1308505	3.8	92.3	0.9733
30	2077	7961	107	235.55	1875395	5.4	97.7	0.9719
31	2082	2150	106	228.81	492016	1.4	99.1	0.9709
32	2084	1160	106	209.41	243024	0.7	99.8	0.9706
TOTALS		151945			34578548	99.8		0.9852

A constant cut of 346513. cu.m. is maintained for 99.8 years.

The expected volume is 341383. cu.m. for a average fire sequence severity.

LONG-TERM EAST SLOPES FIRE RATE - 80 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.45	595508	1.5	1.5	0.9916
2	1986	950	119	206.14	195997	0.5	2.0	0.9805
3	1986	4541	116	212.60	965617	2.4	4.4	0.9642
4	1989	5945	117	246.92	1467929	3.7	8.1	0.9301
5	1993	972	117	171.04	166263	0.4	8.5	0.9068
6	1993	3980	116	212.46	845798	2.1	10.6	0.8926
7	1995	4431	116	217.41	963533	2.4	13.0	0.8694
8	1997	7511	116	209.46	1573329	3.9	16.9	0.8379
9	2001	1754	117	146.77	257532	0.6	17.6	0.8147
10	2002	7543	119	236.34	1782856	4.5	22.0	0.7895
11	2007	1902	121	216.05	410917	1.0	23.0	0.7646
12	2008	5167	120	236.84	1223846	3.1	26.1	0.7466
13	2011	7114	120	219.43	1561198	3.9	30.0	0.7158
14	2014	5907	123	229.42	1355184	3.4	33.4	0.6851
15	2018	5198	121	247.53	1286902	3.2	36.6	0.6591
16	2021	9585	124	221.52	2123408	5.3	41.9	0.6259
17	2026	6869	122	217.40	1493390	3.7	45.6	0.5933
18	2030	4632	124	123.78	573376	1.4	47.1	0.5752
19	2032	692	125	278.59	192840	0.5	47.5	0.5685
20	2032	10557	125	241.54	2550006	6.4	53.9	0.5455
21	2038	10022	129	220.39	2208833	5.5	59.4	0.5085
22	2044	215	124	90.79	19555	0.0	59.5	0.4910
23	2044	211	121	196.88	41600	0.1	59.6	0.4905
24	2044	13029	99	213.09	2776387	6.9	66.5	0.4715
25	2051	230	95	147.53	33961	0.1	66.6	0.4515
26	2051	4801	88	178.05	854876	2.1	68.7	0.4455
27	2053	7693	89	171.22	1317306	3.3	72.0	0.4310
28	2057	118	87	174.84	20788	0.1	72.1	0.4226
29	2057	5697	87	182.84	1041715	2.6	74.7	0.4162
30	2059	7961	89	189.19	1506290	3.8	78.4	0.4008
31	2063	2150	86	178.44	383702	1.0	79.4	0.3891
32	2064	1160	87	163.24	189441	0.5	79.9	0.3855
TOTALS		151945			31979896	79.9		0.6448

A constant cut of 400384. cu.m. is maintained for 79.9 years.

The expected volume is 258167. cu.m. for a severe fire sequence severity.

LONG-TERM EAST SLOPES FIRE RATE - 90 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.51	595690	1.6	1.6	0.9910
2	1986	950	119	206.25	196105	0.5	2.1	0.9789
3	1987	4541	116	212.92	967059	2.6	4.7	0.9614
4	1989	5945	117	247.72	1472706	4.0	8.7	0.9245
5	1993	972	118	172 37	167560	0.5	9.1	0.8994
6	1994	3980	116	213.36	849382	2.3	11.4	0.8844
7	1996	4431	117	218.76	969537	2 6	14.0	0.8599
8	1999	7511	117	211.42	1587989	4.3	18.3	0 8257
9	2003	1754	119	147.21	258302	0.7	19.0	0.8005
10	2004	7543	121	238.53	1799396	4.8	23.8	0.7747
11	2008	1902	123	218.55	415681	1.1	25.0	0.7479
12	2009	5167	122	239.80	1239186	3.3	28.3	0.7283
13	2013	7114	123	222.66	1584141	4.3	32.6	0.6951
14	2017	5907	126	233.17	1377382	3.7	36.3	0.6636
15	2021	5198	124	253.50	1317912	3.5	39.8	0.6351
16	2024	9585	127	227.66	2182315	5.9	45.7	0.6007
17	2030	6869	126	222.65	1529404	4.1	49.8	0.5655
18	2034	4632	129	128.31	594349	1.6	51.4	0.5459
19	2036	692	129	286.08	198023	0.5	51.9	0.5392
20	2036	10557	130	248.43	2622735	7.1	59.0	0.5162
21	2043	10022	135	226.44	2269473	6.1	65.1	0.4766
22	2050	215	130	93.45	20129	0.1	65.2	0.4594
23	2050	211	126	202.45	42778	0.1	65.3	0.4589
24	2050	13029	105	227.05	2958256	8.0	73.2	0.4375
25	2058	230	102	168.16	38709	0.1	73.3	0.4166
26	2058	4801	95	198.64	953716	2.6	75.9	0.4102
27	2060	7693	96	201.72	1551924	4.2	80.1	0.3940
28	2065	118	95	199.84	23761	0.1	80.1	0.3833
29	2065	5697	96	207.37	1181475	3.2	83.3	0.3764
30	2068	7961	98	213.64	1700925	4.6	87.9	0.3598
31	2072	2150	96	204.97	440742	1.2	89.1	0.3470
32	2074	1160	96	187.27	217330	0.6	89.7	0.3432
TOTALS		151945			33324088	89.7		0.6141

A constant cut of 371655. cu.m. is maintained for 89.7 years.

The expected volume is 228234. cu.m. for a severe fire sequence severity.

LONG-TERM EAST SLOPES FIRE RATE - 100 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m / ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.56	595874	1.7	1.7	0.9903
2	1986	950	119	206.37	196214	0.6	2.3	0.9774
3	1987	4541	117	213.24	968518	2.8	5.1	0.9586
4	1990	5945	118	248.54	1477550	4.3	9.3	0.9190
5	1994	972	118	173.72	168877	0.5	9.8	0.8918
6	1994	3980	117	214.17	852607	2.5	12.3	0.8766
7	1997	4431	118	220.14	975638	2.8	15.1	0.8503
8	2000	7511	119	213.40	1602914	4.6	19.7	0.8133
9	2004	1754	120	147.65	259079	0.7	20.5	0.7861
10	2005	7543	122	240.71	1815782	5.2	25.7	0.7599
11	2010	1902	125	221.11	420546	1.2	26.9	0.7309
12	2011	5167	124	242.84	1254868	3.6	30.6	0.7096
13	2015	7114	125	225.53	1604546	4.6	35.2	0.6759
14	2020	5907	128	237.02	1400086	4.0	39.2	0.6417
15	2024	5198	127	258.95	1346233	3.9	43.1	0.6115
16	2028	9585	131	233.69	2240081	6.5	49.6	0.5757
17	2034	6869	130	227.67	1563878	4.5	54.1	0.5384
18	2039	4632	133	132.46	613592	1.8	55.9	0.5188
19	2040	692	134	292.87	202726	0.6	56.4	0.5114
20	2041	10557	135	255.40	2696391	7.8	64.2	0.4862
21	2049	10022	140	231.29	2318107	6.7	70.9	0.4462
22	2055	215	135	96.09	20697	0.1	71.0	0.4279
23	2055	211	132	207.84	43917	0.1	71.1	0.4275
24	2056	13029	112	239.35	3118616	9.0	80.1	0.4060
25	2065	230	109	189.06	43521	0.1	80.2	0.3830
26	2065	4801	102	218.37	1048451	3.0	83.3	0.3763
27	2068	7693	104	231.86	1783863	5.1	88.4	0.3590
28	2073	118	103	222.22	26421	0.1	88.5	0.3472
29	2073	5697	104	229.67	1308505	3.8	92.3	0.3392
30	2077	7961	107	235.55	1875395	5.4	97.7	0.3217
31	2082	2150	106	228.81	492016	1.4	99.1	0.3083
32	2084	1160	106	209.41	243024	0.7	99.8	0.3042
TOTALS		151945			34578548	99.8		0.5845

A constant cut of 346513. cu.m. is maintained for 99.8 years.

The expected volume is 202549. cu.m. for a severe fire sequence severity.

MILD BOREAL FIRE RATE - 80 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.45	595508	1.5	1.5	0.9981
2	1986	950	119	206.14	195997	0.5	2.0	0.9955
3	1986	4541	116	212.60	965617	2.4	4.4	0.9918
4	1989	5945	117	246.92	1467929	3.7	8.1	0.9841
5	1993	972	117	171.04	166263	0.4	8.5	0.9788
6	1993	3980	116	212.46	845798	2.1	10.6	0.9755
7	1995	4431	116	217.41	963533	2.4	13.0	0.9699
8	1997	7511	116	209.46	1573329	3.9	16.9	0.9620
9	2001	1754	117	146.77	257532	0.6	17.6	0.9562
10	2002	7543	119	236.34	1782856	4.5	22.0	0.9499
11	2007	1902	121	216.05	410917	1.0	23.0	0.9431
12	2008	5167	120	236.84	1223846	3.1	26.1	0.9382
13	2011	7114	120	219.43	1561198	3.9	30.0	0.9297
14	2014	5907	123	229.42	1355184	3.4	33.4	0.9209
15	2018	5198	121	247.53	1286902	3.2	36.6	0.9131
16	2021	9585	124	221.52	2123408	5.3	41.9	0.9030
17	2026	6869	122	217.40	1493390	3.7	45.6	0.8924
18	2030	4632	124	123.78	573376	1.4	47.1	0.8864
19	2032	692	125	278.59	192840	0.5	47.5	0.8842
20	2032	10557	125	241.54	2550006	6.4	53.9	0.8765
21	2038	10022	129	220.39	2208833	5.5	59.4	0.8630
22	2044	215	124	90.79	19555	0.1	59.5	0.8566
23	2044	211	121	196.88	41600	0.1	59.6	0.8564
24	2044	13029	99	213.09	2776387	6.9	66.5	0.8490
25	2051	230	95	147.53	33961	0.1	66.6	0.8410
26	2051	4801	88	178.05	854876	2.1	68.7	0.8386
27	2053	7693	89	171.22	1317306	3.3	72.0	0.8327
28	2057	118	87	174.84	20788	0.1	72.1	0.8290
29	2057	5697	87	182.84	1041715	2.6	74.7	0.8262
30	2059	7961	89	189.19	1506290	3.8	78.4	0.8195
31	2063	2150	86	178.44	383702	1.0	79.4	0.8143
32	2064	1160	87	163.24	189441	0.5	79.9	0.8128
TOTALS		151945			31979896	79.9		0.9030

A constant cut of 400384. cu.m. is maintained for 79.9 years.

The expected volume is 361551. cu.m. for a mild fire sequence severity.

MILD BOREAL FIRE RATE - 90 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.51	595690	1.6	1.6	0.9979
2	1986	950	119	206.25	196105	0.5	2.1	0.9952
3	1987	4541	116	212.92	967059	2.6	4.7	0.9912
4	1989	5945	117	247.72	1472706	4.0	8.7	0.9828
5	1993	972	118	172.37	167560	0.5	9.1	0.9771
6	1994	3980	116	213.36	849382	2.3	11 4	0.9736
7	1996	4431	117	218.76	969537	2.6	14.0	0.9675
8	1999	7511	117	211.42	1587989	4.3	18.3	0.9589
9	2003	1754	119	147.21	258302	0.7	19.0	0.9526
10	2004	7543	121	238.53	1799396	4.8	23.8	0.9459
11	2008	1902	123	218.55	415681	1.1	25.0	0 9385
12	2009	5167	122	239.80	1239186	3.3	28.3	0.9331
13	2013	7114	123	222.66	1584141	4.3	32.6	0.9239
14	2017	5907	126	233.17	1377382	3.7	36.3	0.9144
15	2021	5198	124	253.50	1317912	3.5	39.8	0.9058
16	2024	9585	127	227.66	2182315	5.9	45.7	0.8949
17	2030	6869	126	222.65	1529404	4.1	49.8	0.8832
18	2034	4632	129	128.31	594349	1.6	51.4	0.8766
19	2036	692	129	286.08	198023	0.5	51.9	0.8742
20	2036	10557	130	248.43	2622735	7.1	59.0	0.8658
21	2043	10022	135	226.44	2269473	6.1	65.1	0.8510
22	2050	215	130	93.45	20129	0.1	65.2	0.8441
23	2050	211	126	202.45	42778	0.1	65.3	0.8439
24	2050	13029	105	227.05	2958256	8.0	73.2	0 8354
25	2058	230	102	168.16	38709	0.1	73.3	0.8264
26	2058	4801	95	198.64	953716	2.6	75.9	0.8236
27	2060	7693	96	201.72	1551924	4.2	80.1	0.8165
28	2065	118	95	199.84	23761	0.1	80.1	0.8118
29	2065	5697	96	207.37	1181475	3.2	83.3	0.8084
30	2068	7961	98	213.64	1700925	4.6	87.9	0.8004
31	2072	2150	96	204.97	440742	1.2	89.1	0.7943
32	2074	1160	96	187.27	217330	0.6	89.7	0.7924
TOTALS		151945			33324088	89.7		0.8920

A constant cut of 371655. cu.m. is maintained for 89.7 years.

The expected volume is 331519. cu.m. for a mild fire sequence severity.

MILD BOREAL FIRE RATE - 100 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.56	595874	1.7	1.7	0.9978
2	1986	950	119	206.37	196214	0.6	2.3	0.9949
3	1987	4541	117	213.24	968518	2.8	5.1	0.9906
4	1990	5945	118	248.54	1477550	4.3	9.3	0.9815
5	1994	972	118	173.72	168877	0.5	9.8	0.9754
6	1994	3980	117	214.17	852607	2.5	12.3	0.9717
7	1997	4431	118	220.14	975638	2.8	15.1	0 9651
8	2000	7511	119	213.40	1602914	4.6	19.7	0.9558
9	2004	1754	120	147.65	259079	0.7	20.5	0.9490
10	2005	7543	122	240.71	1815782	5.2	25.7	0.9418
11	2010	1902	125	221.11	420546	1.2	26.9	0.9338
12	2011	5167	124	242.84	1254868	3.6	30.6	0.9280
13	2015	7114	125	225.53	1604546	4.6	35.2	0.9181
14	2020	5907	128	237.02	1400086	4.0	39.2	0.9078
15	2024	5198	127	258.95	1346233	3.9	43.1	0.8984
16	2028	9585	131	233.69	2240081	6.5	49.6	0.8866
17	2034	6869	130	227.67	1563878	4.5	54.1	0.8739
18	2039	4632	133	132.46	613592	1.8	55.9	0.8667
19	2040	692	134	292.87	202726	0.6	56.4	0.8641
20	2041	10557	135	255.40	2696391	7.8	64.2	0.8548
21	2049	10022	140	231.29	2318107	6.7	70.9	0.8388
22	2055	215	135	96.09	20697	0.1	71.0	0.8314
23	2055	211	132	207.84	43917	0.1	71.1	0.8312
24	2056	13029	112	239.35	3118616	9.0	80.1	0.8217
25	2065	230	109	189.06	43521	0.1	80.2	0.8116
26	2065	4801	102	218.37	1048451	3.0	83.3	0.8084
27	2068	7693	104	231 86	1783863	5.1	88.4	0.8000
28	2073	118	103	222.22	26421	0.1	88.5	0.7944
29	2073	5697	104	229.67	1308505	3.8	92.3	0.7904
30	2077	7961	107	235.55	1875395	5.4	97.7	0.7812
31	2082	2150	106	228.81	492016	1.4	99.1	0.7741
32	2084	1160	106	209.41	243024	0.7	99.8	0.7719
TOTALS		151945			34578548	99.8		0.8808

A constant cut of 346513. cu.m. is maintained for 99.8 years.

The expected volume is 305214. cu.m. for a mild fire sequence severity.

MODERATE BOREAL FIRE RATE - 80 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.45	595508	1.5	1.5	0.9971
2	1986	950	119	206.14	195997	0.5	2.0	0.9932
3	1986	4541	116	212.60	965617	2 4	4.4	0.9875
4	1989	5945	117	246.92	1467929	3.7	8.1	0.9756
5	1993	972	117	171.04	166263	0.4	8.5	0.9675
6	1993	3980	116	212.46	845798	2 1	10.6	0.9626
7	1995	4431	116	217.41	963533	2.4	13.0	0.9540
8	1997	7511	116	209.46	1573329	3.9	16.9	0.9421
9	2001	1754	117	146.77	257532	0.6	17.6	0.9334
10	2002	7543	119	236.34	1782856	4.5	22.0	0.9239
11	2007	1902	121	216.05	410917	1.0	23.0	0.9138
12	2008	5167	120	236.84	1223846	3.1	26.1	0.9054
13	2011	7114	120	219.43	1561198	3.9	30.0	0.8939
14	2014	5907	123	229.42	1355184	3.4	33.4	0.8809
15	2018	5198	121	247.53	1286902	3.2	36.6	0.8694
16	2021	9585	124	221.52	2123408	5.3	41.9	0.8547
17	2026	6869	122	217.40	1493390	3.7	45.6	0.8393
18	2030	4632	124	123.78	573376	1.4	47.1	0.8306
19	2032	692	125	278.59	192840	0.5	47.5	0.8274
20	2032	10557	125	241 54	2550006	6.4	53.9	0.8163
21	2038	10022	129	220.39	2208833	5.5	59.4	0.7971
22	2044	215	124	90.79	19555	0.0	59.5	0.7880
23	2044	211	121	196.88	41600	0.1	59.6	0.7878
24	2044	13029	99	213.09	2776387	6.9	66.5	0.7772
25	2051	230	95	147.53	33961	0.1	66.6	0.7660
26	2051	4801	88	178.05	854876	2.1	68.7	0.7626
27	2053	7693	89	171.22	1317306	3.3	72.0	0.7544
28	2057	118	87	174.84	20788	0.1	72.1	0.7493
29	2057	5697	87	182.84	1041715	2.6	74.7	0.7454
30	2059	7961	89	189.19	1506290	3.8	78.4	0.7360
31	2063	2150	86	178.44	383702	1.0	79.4	0.7289
32	2064	1160	87	163.24	189441	0.5	79.9	0.7268
TOTALS		151945			31979896	79.9		0.8560

A constant cut of 400384. cu.m. is maintained for 79.9 years.

The expected volume is 342713. cu.m. for a average fire sequence severity.

MODERATE BOREAL FIRE RATE - 90 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization.
1	1985	3394	124	175.51	595690	1.6	1.6	0.9969
2	1986	950	119	206.25	196105	0.5	2.1	0.9927
3	1987	4541	116	212.92	967059	2.6	4.7	0.9866
4	1989	5945	117	247.72	1472706	4.0	8.7	0.9737
5	1993	972	118	172.37	167560	0.5	9.1	0.9650
6	1994	3980	116	213.36	849382	2.3	11 4	0.9597
7	1996	4431	117	218.76	969537	2.6	14.0	0.9504
8	1999	7511	117	211.42	1587989	4.3	18.3	0.9375
9	2003	1754	119	147.21	258302	0.7	19.0	0.9280
10	2004	7543	121	238.53	1799396	4.8	23.8	0.9179
11	2008	1902	123	218.55	415681	1.1	25.0	0.9070
12	2009	5167	122	239.80	1239186	3.3	28.3	0.8990
13	2013	7114	123	222.66	1584141	4.3	32.6	0.8853
14	2017	5907	126	233.17	1377382	3.7	36.3	0.8714
15	2021	5198	124	253.50	1317912	3.5	39.8	0.8588
16	2024	9585	127	227.66	2182315	5.9	45.7	0.8429
17	2030	6869	126	222.65	1529404	4.1	49.8	0.8260
18	2034	4632	129	128.31	594349	1.6	51.4	0.8165
19	2036	692	129	286.08	198023	0.5	51.9	0.8130
20	2036	10557	130	248.43	2622735	7.1	59.0	0.8011
21	2043	10022	135	226.44	2269473	6.1	65.1	0.7801
22	2050	215	130	93.45	20129	0.1	65.2	0.7704
23	2050	211	126	202.45	42778	0.1	65.3	0.7702
24	2050	13029	105	227.05	2958256	8.0	73.2	0.7582
25	2058	230	102	168.16	38709	0.1	73.3	0.7456
26	2058	4801	95	198.64	953716	2.6	75.9	0.7417
27	2060	7693	96	201.72	1551924	4.2	80.1	0.7319
28	2065	118	95	199.84	23761	0.1	80.1	0.7254
29	2065	5697	96	207.37	1181475	3.2	83.3	0.7208
30	2068	7961	98	213.64	1700925	4.6	87.9	0.7099
31	2072	2150	96	204.97	440742	1.2	89.1	0.7015
32	2074	1160	96	187.27	217330	0.6	89.7	0.6990
TOTALS		151945			33324088	89.7		0.8403

A constant cut of 371655. cu.m. is maintained for 89.7 years.

The expected volume is 312295. cu.m. for a average fire sequence severity.

MODERATE BOREAL FIRE RATE - 100 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.56	595874	1.7	1.7	0.9966
2	1986	950	119	206.77	196214	0.6	2.3	0.9921
3	1987	4541	117	213.24	968518	2.8	5.1	0.9856
4	1990	5945	118	248.54	1477550	4.3	9.3	0.9718
5	1994	972	118	173.72	168877	0.5	9.8	0.9623
6	1994	3980	117	214.17	852607	2.5	12.3	0.9567
7	1997	4431	118	220.14	975638	2.8	15.1	0.9468
8	2000	7511	119	213.40	1602914	4.6	19.7	0.9329
9	2004	1754	120	147.65	259079	0.7	20.5	0.9226
10	2005	7543	122	240.71	1815782	5.2	25.7	0.9119
11	2010	1902	125	221.11	420546	1.2	26.9	0.9000
12	2011	5167	124	242.84	1254868	3.6	30.6	0.8913
13	2015	7114	125	225.53	1604546	4.6	35.2	0.8768
14	2020	5907	128	237.02	1400086	4.0	39.2	0.8617
15	2024	5198	127	258.95	1346233	3.9	43.1	0.8480
16	2028	9585	131	233.69	2240081	6.5	49.6	0.8309
17	2034	6869	130	227.67	1563878	4.5	54.1	0.8126
18	2039	4632	133	132.46	613592	1.8	55.9	0.8024
19	2040	692	134	292.87	202726	0.6	56.4	0.7986
20	2041	10557	135	255.40	2696391	7.8	64.2	0.7855
21	2049	10022	140	231.29	2318107	6.7	70.9	0.7630
22	2055	215	135	96.09	20697	0.1	71.0	0.7525
23	2055	211	132	207.84	43917	0.1	71.1	0.7523
24	2056	13029	112	239.35	3118616	9.0	80.1	0.7392
25	2065	230	109	189.06	43521	0.1	80.2	0.7252
26	2065	4801	102	218.37	1048451	3.0	83.3	0.7208
27	2068	7693	104	231.86	1783863	5.1	88.4	0.7094
28	2073	118	103	222 22	26421	0.1	88.5	0.7016
29	2073	5697	104	229.67	1308505	3.8	92.3	0.6963
30	2077	7961	107	235.55	1875395	5.4	97.7	0.6838
31	2082	2150	106	228.81	492016	1.4	99.1	0.6742
32	2084	1160	106	209.41	243024	0.7	99.8	0.6713
TOTALS		151945			34578548	99.8		0.8245

A constant cut of 346513. cu.m. is maintained for 99.8 years.

The expected volume is 285690. cu.m. for a average fire sequence severity.

SEVERE BOREAL FIRE RATE - 80 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.45	595508	1.5	1.5	0.9950
2	1986	950	119	206.14	195997	0.5	2.0	0.9883
3	1986	4541	116	212.60	965617	2.4	4.4	0.9785
4	1989	5945	117	246.92	1467929	3.7	8.1	0.9579
5	1993	972	117	171.04	166263	0.4	8.5	0.9440
6	1993	3980	116	212.46	845798	2.1	10.6	0.9354
7	1995	4431	116	217.41	963533	2.4	13.0	0.9209
8	1997	7511	116	209.46	1573329	3.9	16.9	0.9010
9	2001	1754	117	146.77	257532	0.6	17.6	0.8864
10	2002	7543	119	236.34	1782856	4.5	22.0	0.8705
11	2007	1902	121	216.05	410917	1.0	23.0	0.8540
12	2008	5167	120	236.84	1223846	3.1	26.1	0.8421
13	2011	7114	120	219.43	1561198	3.9	30.0	0.8216
14	2014	5907	123	229.42	1355184	3.4	33.4	0.8008
15	2018	5198	121	247.53	1286902	3.2	36.6	0.7827
16	2021	9585	124	221.52	2123408	5.3	41.9	0.7595
17	2026	6869	122	217.40	1493390	3.7	45.6	0.7359
18	2030	4632	124	123.78	573376	1.4	47.1	0.7226
19	2032	692	125	278.59	192840	0.5	47.5	0.7176
20	2032	10557	125	241.54	2550006	6.4	53.9	0.7007
21	2038	10022	129	220.39	2208833	5.5	59.4	0.6722
22	2044	215	124	90.79	19555	0.0	59.5	0.6587
23	2044	211	121	196.88	41600	0.1	59.6	0.6583
24	2044	13029	99	213.09	2776387	6.9	66.5	0.6431
25	2051	230	95	147.53	33961	0.1	66.6	0.6269
26	2051	4801	88	178.05	854876	2.1	68.7	0.6220
27	2053	7693	89	171.22	1317306	3.3	72.0	0.6102
28	2057	118	87	174.84	20788	0.1	72.1	0.6031
29	2057	5697	87	182.84	1041715	2.6	74.7	0.5977
30	2059	7961	89	189.19	1506290	3.8	78.4	0.5846
31	2063	2150	86	178.44	383702	1.0	79.4	0.5746
32	2064	1160	87	163.24	189441	0.5	79.9	0.5716
TOTALS		151945			31979896	79.9		0.7658

A constant cut of 400384. cu.m. is maintained for 79.9 years.

The expected volume is 306613. cu.m. for a severe fire sequence severity.

SEVERE BOREAL FIRE RATE - 90 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.51	595690	1.6	1.6	0.9946
2	1986	950	119	206.25	196105	0.5	2.1	0.9873
3	1987	4541	116	212.92	967059	2.6	4.7	0.9768
4	1989	5945	117	247.72	1472706	4.0	8.7	0.9546
5	1993	972	118	172.37	167560	0.5	9.1	0.9395
6	1994	3980	116	213.36	849382	2.3	11.4	0.9304
7	1996	4431	117	218.76	969537	2.6	14.0	0.9149
8	1999	7511	117	211.42	1587989	4.3	18.3	0.8933
9	2003	1754	119	147.21	258302	0.7	19.0	0.8774
10	2004	7543	121	238.53	1799396	4.8	23.8	0.8607
11	2008	1902	123	218.55	415681	1.1	25.0	0.8430
12	2009	5167	122	239.80	1239186	3.3	28.3	0.8299
13	2013	7114	123	222.66	1584141	4.3	32.6	0.8078
14	2017	5907	126	233.17	1377382	3.7	36.3	0.7858
15	2021	5198	124	253.50	1317912	3.5	39.8	0.7659
16	2024	9585	127	227.66	2182315	5.9	45.7	0.7413
17	2030	6869	126	222.65	1529404	4.1	49.8	0.7155
18	2034	4632	129	128.31	594349	1.6	51.4	0.7010
19	2036	692	129	286.08	198023	0.5	51.9	0.6959
20	2036	10557	130	248.43	2622735	7.1	59.0	0.6781
21	2043	10022	135	226.44	2269473	6.1	65.1	0.6472
22	2050	215	130	93.45	20129	0.1	65.2	0.6333
23	2050	211	126	202.45	42778	0.1	65.3	0.6329
24	2050	13029	105	227.05	2958256	8.0	73.2	0.6156
25	2058	230	102	168.16	38709	0.1	73.3	0.5980
26	2058	4801	95	198.64	953716	2.6	75.9	0.5925
27	2060	7693	96	201 72	1551924	4.2	80.1	0.5788
28	2065	118	95	199.84	23761	0.1	80.1	0.5697
29	2065	5697	96	207.37	1181475	3.2	83.3	0.5635
30	2068	7961	98	213.64	1700925	4.6	87.9	0.5486
31	2072	2150	96	204.97	440742	1.2	89.1	0.5373
32	2074	1160	96	187.27	217330	0.6	89.7	0.5338
TOTALS		151945			33324088	89.7		0.7425

A constant cut of 371655. cu.m. is maintained for 89.7 years.

The expected volume is 275938. cu.m. for a severe fire sequence severity.

SEVERE BOREAL FIRE RATE - 100 YEAR LIQUIDATION PERIOD

FOREST YIELD PROJECTION SYSTEM

Harvest Projection for Working Circle

The final results are :

Comp. Grp.	Yr. of Entry	Area (ha)	Ave. Age When Cut	-Softwood Volume- (Ave. cubic m /ha)	(Total cu.m.)	Time to Cut	Cum. Time to Cut	Cumulative Probability of Realization
1	1985	3394	124	175.56	595874	1.7	1.7	0.9942
2	1986	950	119	206.37	196214	0.6	2.3	0 9864
3	1987	4541	117	213.24	968518	2.8	5.1	0.9751
4	1990	5945	118	248.54	1477550	4.3	9.3	0.9513
5	1994	972	118	173.72	168877	0.5	9.8	0.9350
6	1994	3980	117	214.17	852607	2.5	12.3	0.9255
7	1997	4431	118	220.14	975638	2.8	15.1	0.9088
8	2000	7511	119	213.40	1602914	4.6	19.7	0.8855
9	2004	1754	120	147.65	259079	0.7	20.5	0.8683
10	2005	7543	122	240.71	1815782	5.2	25.7	0.8509
11	2010	1902	125	221.11	420546	1.2	26.9	0.8316
12	2011	5167	124	242.84	1254868	3.6	30.6	0.8175
13	2015	7114	125	225.53	1604546	4.6	35.2	0.7944
14	2020	5907	128	237.02	1400086	4.0	39.2	0.7705
15	2024	5198	127	258.95	1346233	3.9	43.1	0.7492
16	2028	9585	131	233.69	2240081	6.5	49.6	0.7229
17	2034	6869	130	227.67	1563878	4.5	54.1	0.6952
18	2039	4632	133	132.46	613592	1.8	55.9	0.6801
19	2040	692	134	292.87	202726	0.6	56.4	0.6744
20	2041	10557	135	255.40	2696391	7.8	64.2	0.6549
21	2049	10022	140	231.29	2318107	6.7	70.9	0.6226
22	2055	215	135	96.09	20697	0.1	71.0	0.6076
23	2055	211	132	207.84	43917	0.1	71.1	0.6073
24	2056	13029	112	239.35	3118616	9.0	80.1	0.5890
25	2065	230	109	189.06	43521	0.1	80.2	0.5694
26	2065	4801	102	218.37	1048451	3.0	83.3	0.5634
27	2068	7693	104	231.86	1783863	5.1	88.4	0.5479
28	2073	118	103	222.22	26421	0.1	88.5	0.5374
29	2073	5697	104	229.67	1308505	3.8	92.3	0.5302
30	2077	7961	107	235.55	1875395	5.4	97.7	0.5138
31	2082	2150	106	228.81	492016	1.4	99.1	0.5012
32	2084	1160	106	209.41	243024	0.7	99.8	0.4974
TOTALS		151945			34578548	99.8		0.7193

A constant cut of 346513. cu.m. is maintained for 99.8 years.

The expected volume is 249264. cu.m. for a severe fire sequence severity.

Appendix 2: Summary of Group Consensus

1. Would you use historic fire data in forecasting future annual fire rates? If so, from what period and area would you select data as applicable to a particular management unit such as the McLeod Working Circle? If not, what would you use?

- Historic fire data should be used, but local climate, stand conditions (density, age, species), impact of harvesting, management and access (which will cause fire incidence to increase, but size to decline), and protection effort, should be taken into account.

- Distinguish East Slopes from Boreal Region; note differential drying in East Slopes relative to more uniform drying elsewhere. Fire rates for Edson Forest since protection (c. 1940) will indicate risk associated with normal fire season severity for McLeod W.C. Use age-class data back to mid 1800's to evaluate significance of catastrophes like 1890 fire.

2. Given our observations on the mean age of fire-origin stands relative to cover type and elevation, what do you conclude about the relationship between fire rate and location? Will the relationship change with fire season severity? How would you:

   a. Differentiate locations with respect to probable fire losses?

   b. Priorize stands or compartments for harvesting? To what other stand or site attributes should we attempt to relate fire rate?

Lower fire risk at higher elevations is related to higher stand densities, precipitation, and relative humidity, and to lower temperatures. Fire rates may also be related to drainage, species, and density. Strong seasonal influences occur. Relationships between stand condition and flammability should be clarified; even a very modest resolution would be useful. There is a strong case for exploring adjustment of conventional harvest sequences, in response to perceived hazard differences between locations, to reduce the risk of catastrophic losses.

3. What are the main causes of irregular mortality and volume loss, other than fire, likely to affect stands in the McLeod Working Circle between now and harvest? Comment on the probable nature and magnitude of their effects.

Major risk to first-rotation stands is fire. Mountain pine beetle is less likely, but is a concern as long as large concentrations of 80+ year old timber exist. In second rotation stands major risk is biotic damage up to about 25 years (rabbits, Armillaria, stem rusts), and possible damage by Hylobius, Pissodes, and Atropellis.

4. Given the illustrated relationship between harvest level, rotation, and fire-sequence severity in the hypothetical McLeod Working Circle example, what strategy would you adopt regarding (a) rotations and (b)

annual allowable cut?

- Risk increases significantly if rotation and AAC result in retention of over-mature stands. Consequently, allowable cuts should not be reduced in response to forecast risk, since this will only increase the retention and aggravate the problem.

- The main management strategy available for risk reduction is priorized harvest sequencing.

5. Rate (High, Medium, Low) the following risks to Alberta timber supplies with regard to Magnitude and Urgency. Note also whether the magnitude is increasing, decreasing or fairly constant.

	M	U
a. Fire	H	M-H
b. Deterioration of aspen stands	no consensus	
c. Biotic damage in regenerated softwoods	H	H
d. Mountain pine beetle	H-L	L-M
e. Other (specify)		

Where you identify a high urgency, discuss the implications to (a) specified management decisions and (b) priorities for data collection and research.

- Impact of biotic damage on managed stands (which are typically lower-density than those of fire origin) should be related to decisions regarding management practices, especially stocking control.

- Priorized harvest sequencing to reduce fire danger in natural stands requires an ability to forecast fire hazard changes associated with alternative management plans.